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COGENERATION TECHNOLOGY ALTERNATIVES STUDY (CTAS) UNITED TECHNOLOGIES CORPORATION FINAL REPORT

VOLUME II – INDUSTRIAL PROCESS CHARACTERISTICS

Power Systems Division
United Technologies Corporation

January 1980

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lewis Research Center
Under Contract DEN3-30

for

U.S. DEPARTMENT OF ENERGY
Energy Technology
Fossil Fuel Utilization Division

NOTICE

UNITED TECHNOLOGIES
POWER SYSTEMS DIVISION

February 22, 1980

National Aeronautics and Space Administration
Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Attention: Mr. John W. Dunning, Jr.
MS-500-202

Reference: (1) Contract No. DEN3-30
(2) Letter from Jr. G. J. Barna to Mr. P. Bolan
dated December 21, 1979

The six volumes of the final report of the United Technologies portion of the Cogeneration Technology Alternatives Study under the Reference (1) contract were submitted previously. The Reference (2) letter approved Volumes II, III, and IV with certain modifications.

In accordance with the Reference (1) contract, enclosed are 40 copies and a reproducible copy of Volume II, Industrial Process Characteristics, DOE/NASA/0030-80/2 NASA CR159760 which are submitted in final form.

UNITED TECHNOLOGIES CORPORATION
Power Systems Division

Peter Bolan

Peter Bolan
Program Manager

cc: Mr. L. W. Schopen (W/O Encl.)
Mr. G. J. Barna (W/O Encl.)
Mr. R. Paginton (W/O Encl.)

COGENERATION TECHNOLOGY ALTERNATIVES STUDY (CTAS)

UNITED TECHNOLOGIES CORPORATION FINAL REPORT

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NASA CR 159760

FCR-1333

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Volume II
Industrial Process Characteristics

Prepared for

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21000 Brookpark Road
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U. S. Department of Energy
Energy Technology
Fossil Fuel Utilization Division
Washington, D.C. 20545

Under Interagency Agreement EC-77-A-31-1062

Approved by: ________________ Program Manager
Peter Bolan

UNITED TECHNOLOGIES.
POWER SYSTEMS DIVISION
SOUTH WINDSOR, CONNECTICUT

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Final Report, Prepared Under Interagency Agreement EC-77-A-31-1062. Project Managers, G. Barna and J. Dunning, Power Generation and Storage Division, NASA Lewis Research Center, Cleveland, Ohio 44135.

16. Abstract

The Cogeneration Technology Alternatives Study (CTAS) provides data and information in the area of advanced energy conversion systems for industrial cogeneration applications in the 1985-2000 time period. Six current and thirty-six advanced energy conversion systems were defined and combined with appropriate balance-of-plant equipment. Twenty-six industrial processes were selected from among the high energy consuming industries to serve as a frame work for the study. Each conversion system was analyzed as a cogenerator with each industrial plant. Fuel consumption, costs, and environmental intrusion were evaluated and compared to corresponding traditional values. Various cogeneration strategies were analyzed and both topping and bottoming (using industrial by-product heat) applications were included.

The advanced energy conversion technologies indicated reduced fuel consumption, costs, and emissions. Typically fuel energy savings of 10 to 25 percent were predicted compared to traditional on-site furnaces and utility electricity. With the variety of industrial requirements, each advanced technology had attractive applications. Overall, fuel cells indicated the greatest fuel energy savings and emission reductions. Gas turbines and combined cycles indicated high overall annual cost savings. Steam turbines and gas turbines produced high estimated returns. In some applications, diesels were most efficient. The advanced technologies used coal-derived fuels, or coal with advanced fluid bed combustion or on-site gasification systems.

This volume presents industrial processes data and information developed by Gordian Associates, Incorporated used in the study.

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VOLUME II

PREFACE

The Cogeneration Technology Alternatives Study (CTAS) was performed by the National Aeronautics and Space Administration, Lewis Research Center, for the Department of Energy, Division of Fossil Fuel Utilization. CTAS was aimed at providing information which will assist the Department of Energy in establishing research and development funding priorities and emphasis in the area of advanced energy conversion system technology for advanced industrial cogeneration applications. CTAS included two Department of Energy-sponsored/National Aeronautics and Space Administration-contracted studies conducted in parallel by industrial teams along with analyses and evaluations by the National Aeronautics and Space Administration's Lewis Research Center.

This document describes the work conducted by Power Systems Division of United Technologies Corporation under National Aeronautics and Space Administration contract DEN3-30. This United Technologies contractor report is one of a set of reports describing CTAS results. The other reports are the following: Cogeneration Technology Alternatives Study (CTAS) Volume I - Summary NASA TM 81400, Cogeneration Technology Alternatives Study (CTAS) General Electric Final Report NASA C.: 159765-159770 and Cogeneration Technology Alternatives Studies (CTAS) Volume II - Comparison and Evaluation of Results, NASA TM 81401.

This United Technologies contractor report for the CTAS study is contained in six volumes:

Volume I	- Summary Report, DOE/NASA/0030-80/1 NASA CR 159759
Volume II	- Industrial Process Characteristics, DOE/NASA/0030-80/2 NASA CR 159760
Volume III	- Energy Conversion System Characteristics, DOE/NASA/0030-80/3 NASA CR 159761
Volume IV	- Heat Sources, Balance of Plant, and Auxiliary Systems, DOE/NASA/0030-80/4 159762
Volume V	- Analytic Approach and Results, DOE/NASA/0030-80/5 159763
Volume VI	- Computer Data, DOE/NASA/0030-80/6 NASA CR 159764

The data and information presented in this Volume II were developed by Gordian Associates, Incorporated, of New York, New York.

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VOLUME II

INTRODUCTION

The Cogeneration Technology Alternatives Study evaluated advanced energy conversion technologies in industrial cogeneration applications. In the conduct of this study, information and data had to be developed for (1) industrial processes in energy intensive industries; (2) both current and future energy conversion characteristics; (3) heat sources as required by the conversion systems; (4) supporting technologies; (5) balance of plant; and (6) study ground rules and assumptions. These data were analyzed and conservation, economic, and environmental impacts of advanced energy conversion technologies in cogeneration applications were evaluated at the plant level and extrapolated to the potential national level.

The study in its entirety is summarized in Volume 1 of this report. A series of five additional volumes provide more detailed data and information which were the basis for this study.

In order to provide a valid framework for the evaluation of advanced conversion cogeneration systems, representative industrial processes were selected from energy-intensive industries. The selected processes were expected to be significant energy consumers in the 1985 and 2000 time period. They reflect a variety of fuel and electrical power requirements and they currently consume substantial amounts of oil and gas. Therefore, they are candidate applications for conversion to coal or alternate fuels.

The industrial processes selected for use in this study are:

1. Meat Packing and Meat Processing
2. Baking
3. Malt Beverage Production
4. Textile Mills
5. Sawmills
6. Newsprint Mills
7. Writing Paper Mills
8. Corrugated Paper Mills
9. Boxboard Mills
10. Chlorine - Caustic Production
11. Alumina Production
12. Low Density Polyethylene Production
13. High Density Polyethylene Production
14. Polyvinyl Chloride Production
15. Butadiene Rubber Production
16. Nylon Production
17. Styrene Production
18. Ethylene Production
19. Petroleum Refinery
20. Tire Production
21. Steel Production
22. Gray Iron foundries
23. Copper Production (Arbiter Process)
24. Motor Vehicle Assembly
25. Glass Container Production
26. Cement Production

The selected industries are arranged by Standard Industrial Classification (SIC) developed by the Federal Government which classifies manufacturing and industrial plants and establishments in accordance with their products. There is a wide variation in energy consumption from category to category because of the nature of the products and the structure of the classification system.

The last two processes are candidates for back-end or bottoming cogeneration applications; that is, heat derived from the industrial process is converted to electricity. All of the other processes are candidates for front-end or topping cogeneration systems where the energy conversion system provides both electricity and heat.

This Volume II presents the information and data developed by Gordian Associates Incorporated, for each of the selected 26 industrial processes. Each section of this volume presents the following information for one of the selected industrial processes:

1. A description of the process including the annual energy consumption and product production and plant capacity

2. The energy requirements of the process for each unit of production and the detailed data concerning electrical energy requirements and also hot water, steam, and direct fired thermal requirements

3. Anticipated trends affecting energy requirements with new process or production technologies

4. Representative plant data including capacity and projected requirements through the year 2000.

In order to provide the most useful framework for the evaluation of cogeneration systems in the selected potential industrial applications, a wide variety of information and data pertaining to the energy-consuming characteristics of these industrial processes was assembled. This information is presented in the chapters which follow, all of which are structured in the following basic fashion:

Process Identification

SIC Classification - provides the 4-digit SIC industry to which the process belongs

Process Description - provides a general description of the process including, for example, input materials and product output, a listing of unit operations, and a discussion of the major energy uses.

National Data

Capacity and Production Data - provides the approximate national industry capacity and production employing the process, the range of existing plant capacities, and typical plant capacities for the present and future.

Annual Energy Consumption - provides the total estimated national energy consumed by each process for the base year.

Process Energy Requirements

Unit Energy Consumption Data - provides the average energy consumption per unit of primary process output, and a breakdown of the energy sources (e.g., electricity, oil, coal, etc.) presently used.

Details of Electricity and Thermal Energy Consumption - provides comprehensive data on the form of energy input to the process, including a breakdown of steam (by temperature level), hot water, and direct-fired fuel, and process fluid exhaust streams and conditions.

Anticipated Trends

Product Growth Trends - provides estimates of growth trends for the process products in the 1985-2000 time period.

Process Changes - provides descriptions of alternative process technologies feasible for implementation in the 1985-2000 time period.

Implementation of New Technology - provides estimates of the degree to which process changes are likely in the 1985-2000 time period as a result of environmental regulations, energy conservation measures, fuel availability, availability of raw materials and other factors.

Trends in Energy Requirements - provides the total national energy consumed by the process in a base year and estimates consumption for the years 1985 and 2000, broken down by energy source and fuel type. Also provides estimates of likely changes in the mix of fuels used, and in the quantities of steam, electricity and total fuel consumed per unit of product in the 1985-2000 time period.

Plant-Specific Data

Load Profiles - provides thermal and electrical load profiles or load factors for typical work days and non-work days in a typical plant. Also describes significant deviations from the typical profile.

Energy Flow Schematics - provides simplified energy flow schematics (electrical and thermal) for the typical plant, illustrating energy needs by process stage.

State Conditions and Mass Flows - provides process conditions (e.g. temperature and pressure) and material consumption data.

Reliability Considerations - provides an indication of the criticality of power failures, and the ability of the process to withstand interruptions in its energy supply.

Furthermore, in order to ensure consistency in both the data generated and the format in which they are reported, a number of groundrules were formulated. The basic groundrules are as follows:

- the base year for which data is reported in 1975. In specific cases where more recent data were available, these data are also provided.
- electrical energy consumption, when reported on a BTU basis, refers to electrical BTUs delivered, i.e. not including inefficiencies of power generation.

- the term "productive day" refers to any day in which production takes place, i.e. not necessarily a 24 hour workday.

- "double entry bookkeeping" has been used to account for fuel credits accruing to processes, i.e. the total gross energy required in a process includes any and all fuel credits generated. Thus, the net energy required in a process is the difference between the gross energy requirement and the energy credits (if any).

- wherever feasible information has been provided on a quantitative basis. In areas where this proved impractical, qualitative judgements have been provided. Particularly in projecting trends, some cases have been found to be non-quantifiable. However, each of these cases has been examined individually and categorized as an area in which changes are either likely, unlikely, or impossible due to technical or other constraints.

MEAT PACKING

1.0 PROCESS IDENTIFICATION

1.1 SIC Classification

The Meat Products Industry, as defined by SIC 201, is divided into four sub-industries; this discussion is limited to the meat packing (SIC 2011) and meat processing (SIC 2013) industries*, with primary emphasis on SIC 2011. These two industries form the middle link in the chain of livestock/meat production/market. Establishments classified under SIC 2011 and 2013 are primarily engaged in the following activities:

SIC 2011: Meat Packing Plants, which slaughter meat animals and may or may not perform further processing operations.

SIC 2013: Sausage and other prepared meats, which includes plants that produce a wide variety of meat products, but do not slaughter.

1.2 Process Description

Meat packing plants are classified as slaughter, process or integrated. Slaughter plants basically kill and dress the animal for subsequent sale. In process plants, no slaughter occurs, but a wide range of meat products are produced. Integrated plants combine the features of the other two and can perform a complete range of operations from slaughter to canning. A breakdown of these federally inspected plants, by type, is given below**, as reported for mid 1977:

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* The other two industries are Poultry Dressing Plants (SIC 2016) and Poultry and Egg Processing (SIC 2017).

** Meatfacts 1977 (American Meat Institute, Washington, D.C. 1977)

	% of total Plants	% of total Production
Slaughter only	6	60
Integrated	21	30
Process only	73	10
	100	100

At this point an important characteristic of the meat packing industry must be mentioned: there is no single "typical" plant in this industry. Each plant produces a different mix of products and each may perform similar operations in a different manner. It should therefore be noted that in the following discussion, generalizations must be made and that something that may apply in one plant might not apply in another because of the diversity within the industry.

Each process in a meat packing plant can be assigned either to the slaughtering sector or the processing sector. Exhibit 201-1 is a diagram of material and energy flows for the slaughtering sector. The number of processes present, and the manner in which they are carried out, varies widely from plant to plant. The product may leave the plant in various forms, ranging from a chilled whole carcass to boxed retail meat cuts. Rendering materials and products used for sausage making and prepared meat processing may be sold to other plants or processed on site. Exhibits 201-2, 201-3 and 201-4 are diagrams of material and energy flows for three areas of the processed meat sector: ham, bacon and picnics, sausage, and canned meat products. The following paragraphs describe the basic processes and operations used.

Upon receipt, the livestock is penned, usually for less than one day before slaughter. After being taken from the pens, the animals are immobilized either by chemical, electric or mechanical means and are hoisted and conveyed for sticking and bleeding. Cattle hides are then

removed by manual or mechanical means, as are those of sheep, lamb and calves. Hogs are usually not skinned but are passed through a scalding tank, singed and shaved for final hair removal, and sprayed with water prior to evisceration.

The animal carcass is then opened and the animal is eviscerated. The heart, liver, tongue, head meat, brains and kidneys are removed and washed; these may be sold as edible meat or are used in meat products. The balance of the viscera is sent on to a viscera handling subprocess. Most of the blood is either processed on site or sent elsewhere for processing; as a rule, only very small plants discard the blood. The intestines may be rendered, although hog intestines are still used to some extent as sausage casings and beef paunches and hog and sheep stomachs and intestines are often washed and used for edible products. The cattle and calf hides may be brine cured or salted and stacked in a curing room after demanuring, washing and defleshing.

The production of hams and bacon involves preparation of the meat (mostly cutting) prior to the injection or application of a pickle solution. The product is then cooked and smoked. Subsequently, the product is cooled, aged and prepared for marketing.

Actual energy consumption and fuel type will vary from plant to plant due to the great diversity in product mix. At the present time, natural gas is the energy source most commonly used in meat packing facilities. However, due to recent curtailments of natural gas, most facilities are making provisions to have standby fuel oil or LPG available.

The major use of natural gas is for raising steam for plant use. Plants which slaughter hogs also use natural gas for singeing. Some plants may use natural gas to run refrigeration compressors.

Steam consumption is for water heating and cooking. The hot water is used extensively for cleaning up operations. Other uses of steam include rendering, space heating and in some cases steam is used to power turbines for on site electric energy generation.

Electric energy's greatest use is for refrigeration. Other areas of consumption include lighting, kill room operation, and meat processing.

2.0 NATIONAL DATA

The annual national data for the meat packing industry is shown in Exhibit 201-5. The following sections discuss production and energy consumption.

2.1 Capacity and Production Data

As of March 31, 1977 there were over 6,000 meat packing and processing plants operating under federal inspection in the United States; these are generally larger plants which prepare products for interstate sale. While these plants account for over 90% of the nation's meat production, there are an additional 6,000 meat packing plants operating under state or local regulation. The number of federally inspected plants are listed in Exhibit 201-6 by regions.

The North Atlantic, North Central and Pacific regions showed the highest concentration of plants; however, the meat packing plants are shown to be well dispersed geographically in order to be near their markets.

Those slaughtering plants can be further broken down by plant size as shown in Exhibit 201-7. It can be seen that a large number of large capacity plants exist for cattle and hogs while the plants for slaughtering calves and sheep are much smaller.

In general, plants vary in size from a few thousand animals slaughtered annually (with only three days of slaughtering per week) to the very large plants over a million animals per year in multishift operations. In terms of tons of product per hour, sizes range from 1 to 53 tons/hours, with the model or "typical" size estimated to be about 40 tons/hour. Based on a typical two shift operation six days a week, this is equivalent to about 200,000 tons per year.

Production and consumption of all forms of meat slaughtered is in fairly close balance due to the perishability of those products. It can be seen in Exhibit 201-8 that, over the past 15 years, beef production has continued to rise and veal and lamb production have had a long term downtrend, while pork production has held about the same level of production.

2.2. Annual Energy Consumption

The U.S. Census Bureau reports the following consumption of energy in 1975 by SIC codes 2011 and 2013[1] (also shown in Exhibit 201-5).

1975 ENERGY CONSUMPTION

ENERGY SOURCE	CONSUMPTION (TRILLION BTU)	
	SIC 2011	SIC 2013
Distillate Oil	4.3	4.4
Residual Oil	3.4	-
Coal	11.8 (a)	-
Natural Gas	36.0	5.6
Other Fuels	2.1 (b)	1.4
Electricity (c)	13.0	4.6
Total Purchased Energy	70.6	11.4

(a) By difference - not reported
(b) Gordian estimate
(c) Assuming 3413 BTU/KWH

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(1) U.S. Department of Commerce, "Annual Survey of Manufactures", Fuels and Electric Energy Consumed, 1975 Edition.

3.0 PROCESS ENERGY REQUIREMENTS

The sub-sections describe the energy consumed per unit of production in meat packing and meat processing. A summary of the energy requirements per unit output appears in Exhibit 201-9.

3.1 Unit Energy Consumption Data

As seen in section 2.2 and in Exhibit 201-5, the meat packing industry (SIC 2011) used 70.6 trillion Btu of energy in producing 31.8 billion pounds of meat in 1975 (2, 200 Btu/pound, on average). In the processing side of the industry (SIC 2013) 16.0 trillion Btu were consumed to produce 5.1 billion pounds of product (3140 Btu/pound, on average).

The energy consumed in the slaughtering operation varies as a function of the degree of prior processing and the type of animal being processed. This can be, seen from data presented in a recent study[1].

Plant Activities	Beef Plant BTU/lb Live Weight)	Hog Plant BTU/lb Live Weight
Slaughter and by product processing	750	1400
Slaughter to primal cutting	1130	1900
Slaughter to boxing	1500	-

The meat processing part of the industry is more energy intensive than slaughter. The same report provided the following estimates of the total Btu requirements per pound of finished product:

(1) Development Planning and Research Associates, Inc., Industrial Energy Study of Selected Food Industries, prepared for Federal Energy Administration, 1974 (NTIS PB 237316)

Smoked, cooked and other pork	10,000
Dry and semidry sausage	12,000
Fresh sausage	1,500
Frankfurters, luncheon meats and jellied products	3,200
Canned meats	4,500

Unit energy consumption by type, used in an integrated meat packing plant is summarized in Exhibit 201-9.

Actual energy consumption and fuel type will, as previously mentioned, vary from plant to plant due to the great diversity in product mix. A recent study of five representative plants, performed by Johns Manville[1] provided detail on thorough energy audits which were performed in each plant. The patterns of fuel use within these plants are examined in Exhibits 201-10 through 201-12. The plants are described as follows:

Plant "A" is a medium size packing plant of about 100 employees, located in Iowa. The basic process is a straight cattle slaughter, wholesale operation with no cutting or processing of meat. About five hundred head of cattle are slaughtered and cooled per day, and shipping generally takes place within 24 hours after slaughter. The basic products are cooled carcass sides and frozen boxed edible offal products. The plant operates on a one shift, five day operation, although six day operation is occasionally required.

In this plant electricity is used primarily for refrigeration. Natural gas is almost exclusively used for steam generation. Steam is used for hot water generation and rendering.

Plant "B" is a medium size packing plant of about 300 employees. The basic process is straight hog slaughter and fresh meat cut with no

(1) Johns-Manville Corporation, A Study of Energy Conservation Potential in the Meat Packing Industry, prepared for the Federal Energy Administration, May 1976.

cooking smoking, or other processing of meats. Approximately 2400 hogs are slaughtered daily; the cutting occurs after cooling. Basic products include fresh pork cuts and frozen meats. The plant operates on a one shift, five day operation, and is located in Iowa.

Although no breakdown on electrical consumption was provided for this plant, the major consumption of electricity is for refrigeration and the processing plant. Natural gas is used for steam generation and singeing. Steam is used for hot water generation, and rendering.

Plant "C" is a small size plant of about 35 employees located in Wisconsin. About 30-50 cattle and 20-30 hogs are slaughtered each week, with a few calves and lambs on occasion. Meat is cut, aged and sold fresh, or further processed by smoking and curing. Products include pork and beef sausages, hams, bacon and fresh cut meats. Meat cutting and processing occurs over one shift, five days per week; slaughter generally occurs one or two days per week.

Electricity is used primarily for refrigeration with other uses throughout the slaughtering and processing areas. Natural gas is used primarily in the cured meat/smokehouse area with a small amount used to fire a small steam boiler. The steam is used in the smokehouse area and for sterilization.

Plant "D" is a small size packing plant of about 18 employees located in Wisconsin. The basic process is slaughtering of 30-50 cattle and 20-30 hogs per week, and occasionally a few calves and lambs. Meat is aged, cut, and sold fresh or further processed by curing and smoking. Products are retail and wholesale pork and beef sausages, hams, bacon, as well as fresh meat cuts. By-products, such as hides, offal, etc., are sold in bulk for processing elsewhere.

Electricity is used primarily for refrigeration, with small amounts for lighting and processing. Natural gas is used for steam and meat curing. A breakdown of steam consumption was not provided in the report.

Plant "E" employs about 1000 people and is a large size packing plant located in Nebraska. The basic process is slaughter of cattle and hogs, cutting and deboning, and processing by curing, smoking, canning and cooking. The primary products are fresh cuts, smoked meats, bacon, sausages and canned meat. From 3500 to 4000 hogs and 400 to 500 cattle are slaughtered daily during the first and second shifts, five days per week operation. Processing of canned meats is carried out in the first and second shifts while clean up is performed on the second and third shifts.

The plant uses a large amount of electricity, for refrigeration and lighting, with the largest single use is in the processing area. Natural gas is used primarily for steam generation but is also used for hog singeing and in the process plant. Steam is used throughout the operation with about one half used for hot water.

This plant would be considered "typical" of the type of plants accounting for the majority of output in the meat packing industry.

Since Plant E can be considered "typical" of the integrated plants accounting for the majority of output in the meat industry, detailed unit energy consumption data are presented for this facility in Exhibit 201-9. Plant E uses steam, hot water and electricity as well as some direct fuel. A unit of output for Plant E denotes one ton of meat product.

Steam is generated at over 500°F and let down through a turbine to produce mechanical work for driving refrigeration compressors. About 2.56×10^6BTu/Ton of steam are raised, with 0.20×10^6 BTu/Ton of mechanical work extracted; the remaining 2.36×10^6BTu/Ton of steam are used at temperatures up to 300°F, for process uses and generation of hot water.

Electrical requirements for Plant E are 0.62×10^6BTu/Ton, where electrical energy is converted to BTu's using 3413 Btu/kWh.

Meat packing facilities use large quantities of hot water. Unit consumption of hot water in Plant E is 1.47×10^6 BTu/Ton. The majority of the hot water (1.37×10^6BTu/Ton) is generated from the steam, while the remainder is generated from waste heat.

For the purpose of this report the shaft work supplied by the steam was considered to be supplied by electric energy. Steams used for generating hot water is not shown under steam use but is shown under hot water use. Thus in Exhibit 201-9 unit energy usage is 10^6 Btu per ton are shown as; 0.89 for electric energy, 1.47 for hot water and 0.99 for steam.

3.2 Details of Electrical Consumption

In meat packing plants purchased electricity supplies most of the electrical needs. Smaller facilities have no alternatives to buying from commercial sources but a few of the larger facilities have steam turbines that generate a portion of their power requirements, co-generating electricity, steam, and hot water. Many smaller meat packing plants operate on a one-shift, five day week basis while other larger plants work on a two and occasionally a three shift basis. The operations vary during the day and this variation is reflected in varying electrical demands.

As previously mentioned, one of the major uses for electrical power is for refrigeration, which has a constant 24 hours load; however, processing requirements vary during the working day.

Electrical power use in Plant E is distributed among major functions as follows:

	%
Lighting	19
Process Equipment	36
Refrigeration	24
Other	21
	100%

It should also be noted that a large portion (about 57%) of the refrigeration in Plant E is supplied as mechanical shaft power from steam. This is not an unusual practice in larger integrated plants, but is seldom found in smaller plants.

3.3. Details of Thermal Energy Consumption

Thermal energy in meat packing plants is primarily in the form of steam and hot water, although some natural gas is used directly for hog singeing or, in some cases, to fuel refrigeration equipment.

Steam is used for hot water heating and cooking. It is also used for space heating and sterilization.

When steam turbines are operated, high pressure superheated steam (300 psig, 580°F) is required; saturated steam at 70-110 psig is sufficient for use in blood cooking, rendering and processing. Only 15 psig exhaust steam is required for hot water heating and space heaters.

Steam in Plant E is divided among its major uses as follows:

	%
Hot Water Raising	54
Mechanical Work	8
Cooking/Rendering	21
Other	17
	100%

4.0 ANTICIPATED TRENDS

This section discusses trends in production levels, process technology and energy consumption in meat packing and processing industry that are likely to occur to the year 1985 and 2000.

4.1 Product Growth Trends

For the time period 1960-1976, as was seen in Exhibit 201-8, there has been a steady increase in beef production, a decrease in veal and lamb production and essentially no change in pork production. The per capita consumption of red meat for this same time period is shown in Exhibit 201-13. The total consumption growth rate for this period is 2.8 percent/year. This trend is typical of industrialized nations where the per capita consumption of beef rises more rapidly than other forms of meat as the Gross National Product rises.

This same growth rate for total meat slaughtered (SIC 2011) is expected to continue to 1985. In the period 1985 to 2000 the rate of growth is expected to drop as the population growth decreases. A growth rate of 1.4 percent/year is expected for 1985-2000.

The production of processed meats was previously presented and is shown in Exhibit 201-15. The historical growth rate for this production (SIC 2013) is 3.7 percent/year and this is expected to continue until 1985. The growth rate for the period 1985 to 2000 should slow to 2.0 percent/year.

These data and forecasts are shown in Exhibit 201-14 and are summarized as follows:

	Production (Million Tons)		
SIC	1975	1985	2000
2011	15.9	20.9	25.9
2013	2.6	3.7	5.0

4.2 Process/Technology Changes

Between now and the year 2000, there are several changes in processing technology that could increase the efficiency of the meat packing industry both in meat output per carcass and the energy required per pound of product. Several of these are listed below:

- Mechanical deboning of meats[1] and its subsequent use in a wide variety of edible meat foods is by far the most promising technological contribution in the foreseeable future. With the equipment available today and the mechanical improvements on the horizon, one should be able to recover approximately 3-4 pounds of pork/carcass and some 13-16 pounds of beef/carcass that would normally go to rendering. This could add 1 billion pounds of additional meat to our supply if all beef and pork slaughtered were to be mechanically deboned, an increase of approximately 3 percent to supply. This mechanical deboning could be implemented to some degree within 5 years depending upon customer acceptance of the product. However the impact of this technological advance on energy consumption per pound of meat processed will be negligible.

(1) "Recaptured Protein", Meat Processing, (November 25, 1977): 76-78.

- Certain energy saving alternatives to present beef handling methods include conveyerized cooling and boneing immediately after slaughter[1]. The new process could cut energy consumption in cooling by 30 percent or more. Taking the product off the bones and using conveyerized coolers could result in considerable reduction in cooling space. Cutting out bones and fat, which constitute about 30 percent of the weight of a side of beef before chilling, would reduce energy consumed in chilling. This reduction in refrigeration requirements could result in savings of greater than 1 percent of total energy used in the industry. These techniques, if fully developed, could be instituted in the industry within the next 10 years, but would probably be initiated only in new, larger plants as they are built.
- A new packing technique[2] of sealing meat in an aluminum foil plastic film laminate before sterilization could reduce the time period required for sterilization by about one third of the time needed for canned products. This would reduce the amount of heat required for sterilization. This process has been tested and is ready to be used by the Army to replace k-rations within 1-2 years.

4.3 Trends in Energy Requirements

The FEA "Target" for the meat packing industry is a 12 percent reduction in energy use per unit of production by 1980 relative to 1972

(1) "Energy": The Changed and Changing Scene" Institute of Petroleum Summer Meeting (New York: Asiatic Petroleum Corp., 1973) 10

(2) "Meat In a Pouch", Meat Industry (November 1977): 22-23.

energy consumption levels[1]. The same study indicated that it is technologically feasible to reduce unit energy consumption by as much as 17 percent in the same time frame. Assuming a 17 percent reduction relative to present energy consumption levels could be achieved by 1985, Exhibit 201-15 illustrates probable annual energy consumption levels for the industry in that year.

Due to the great interest in energy savings it would be expected that an additional 5 percent in energy reduction could be achieved by 2000. Energy consumption levels for the year 2000 are presented in Exhibit 201-15.

The largest energy savings will come from the more efficient use of boiler fuels. This will be in the form of reduction of boiler losses, the more efficient heating of feedwater, the recovering of waste energy from rendering processors, and the more efficient use of hot water. The composite industry boiler efficiency is currently about 74 percent. Boiler losses could be reduced 18 percent by better operating procedures and addition of heat exchangers, air atomizers and condensate return equipment.

To insure these energy savings some of the industry trade associations have started a program for increasing the energy conservation awareness within their particular industries. For example, the American Meat Institute, National Independent Meat Packers Association, and Western Meat Packers Association have jointly sponsored "Meat Industry Energy Conservation Workshops:" designed on a very practical level to provide ideas, stimulate thinking, and create an awareness of energy saving ideas for plant engineers, and other personnel.

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(1) Development Planning and Research Associates, Inc., Energy Efficiency Improvement Targets - Food and Kindred Products Industry, Support Document, prepared for FEA 1976 (CR-04-6-603)69.

5.0 PLANT-SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements. Load profiles, process conditions and reliability conditions are discussed. These data are derived from plants evaluated in the Johns Manville study. Various plant factors are summarized in Exhibit 201-22.

5.1 Load Profiles

In meat packing plants slaughtering may occur every work day but in some smaller plants it may occur only a few days each week. The steam load varies during the day as the slaughtering process goes from killing to rendering to cleanup times. This cycle is seen in Exhibit 201-16. This particular load profile is for a small plant where only slaughtering is performed. The chilling process continues for a 24 hour period and the electricity load as shown in Exhibit 201-17 would be typical for a "slaughtering only" plant.

The slaughtering/processing operation was described in Section 1.2 and material and energy flows were depicted in Exhibits 201-1 through 201-4. The major energy consumption areas in several "typical" plants were presented in Exhibits 201-10 through 201-12. These energy load patterns are summarized in Exhibit 201-18.

The energy consumption loads for gas and electricity during a workday reflects the operation as was shown in Exhibit 201-16. Slaughtering usually occurs during the day and the rendering and processing operations reach a peak during the latter part of the day. The late shift is usually devoted more to cleaning and processing, with a corresponding

drop in energy requirements. The processing side of the operation exhibits a reasonably level energy demand, as the meat is fed to those operations on a more constant basis.

Since plant "E" of the Johns Manville study incorporates most of the processes included in the meat packing/processing industry, one can consider energy consumption data from this plant as representing a large portion of the industry "typical" in terms of pounds of production and therefore type and amounts of energy consumed.

There is some seasonal variation in energy requirements for Plant E due to changes in space heating requirements. However, the energy load/pound of production is fairly constant. The load curves for electricity, steam, and hot water are shown in Exhibits 201-19 through 201-21.

For a "typical" meat packing plant the ratio of electrical energy to thermal energy consumed is about 0.3 (Exhibit 201-18). The minimum E/T of 0.10 occurred on a mid winter weekday, giving a coincidence factor of 0.3.

5.2 Energy Flow Schematics

Material and energy flows for slaughter and processing of meat was shown in Exhibits 201-1 through 201-4. These flow schematics combined with the detailed energy consumption data shown in Exhibits 201-11 through 201-13 lead to several observations.

- The principal use of natural gas is for steam generation. Fuel oil is also used for this in peak times of year when gas is curtailed. Some gas is used for hog singeing and space heating.
- The greatest uses for steam are for generating hot water and for rendering.

- The greatest use of electricity is for refrigeration and power driven equipment in the processing plant.

5.3 State Conditions and Mass Flows

The steam used in a meat packing plant is 300 psig or less depending on whether it is being used to heat water and spaces or in rendering. For rendering and cooking purposes saturated steam (300 or 110 psig) would be sufficient, however, if the steam is to be used for power generation 300 psig steam superheated to 585°F would be needed. The large requirements for hot water in the plant can usually be satisfied with the use of 15 psig exhaust steam.

A process schematic showing energy uses is shown in Exhibit 201-23.

5.4 Reliability Considerations

Electric power outages of 3 to 4 hours are unlikely to have any serious effects on a plant such as "E." Power outages of larger duration (24 hours or more) would cause serious disruption, since freshly killed animals must be cooled 24 hours prior to processing. Meat and meat products stored under refrigeration could also spoil in the event of prolonged outage.

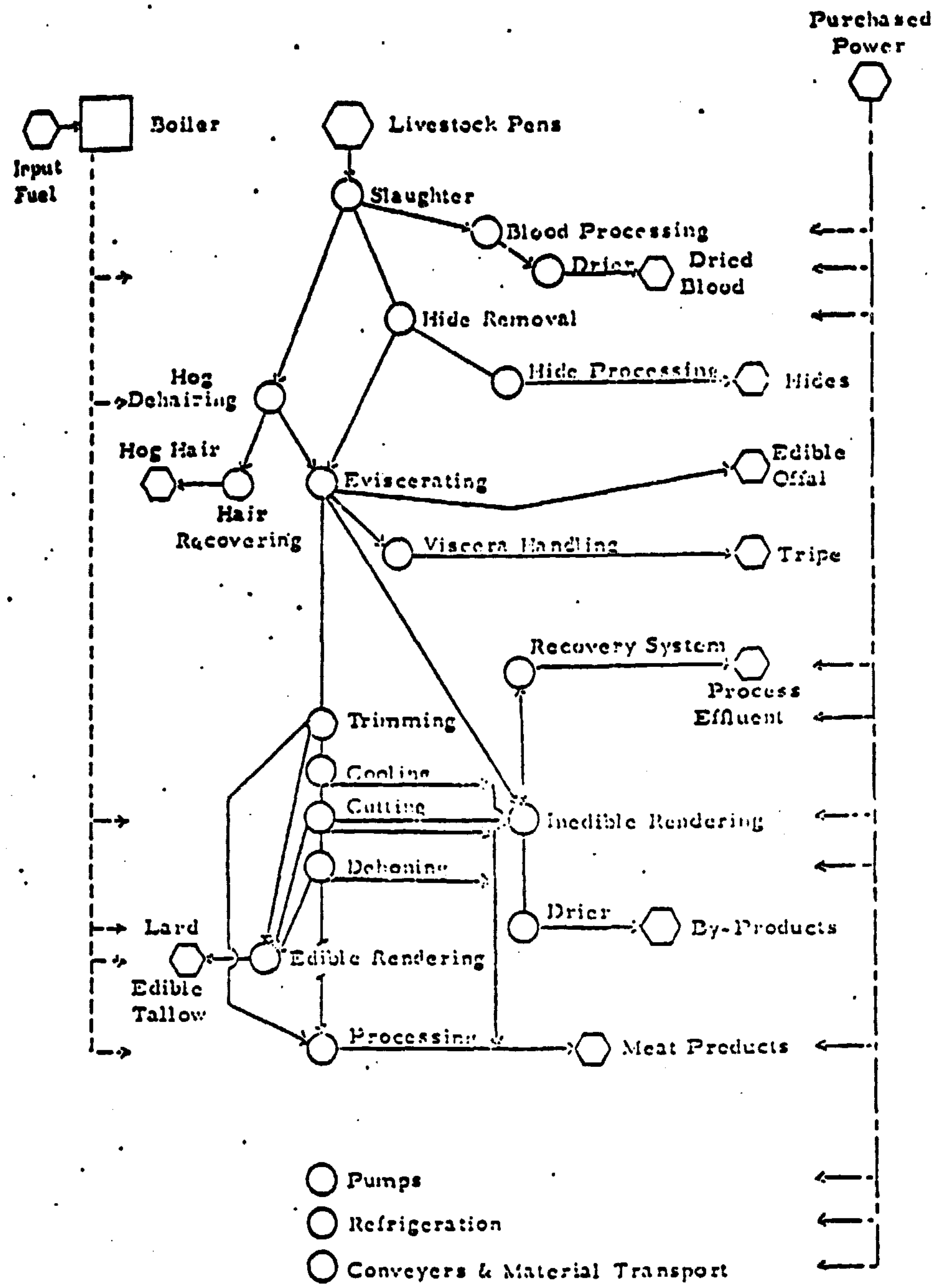
In recent years the curtailment of natural gas has been a problem, however most of the steam boilers have been equipped to handle standby fuel such as fuel oil or LPG. Some of the older boilers can handle coal while some of the small-newer boilers can handle only natural gas. Without steam the plants cannot operate.

Some representative plant factors are shown in Exhibit 201-22.

EXHIBIT 201-1

DIAGRAM OF MATERIAL AND ENERGY FLOWS FOR MEAT PACKING PLANTS

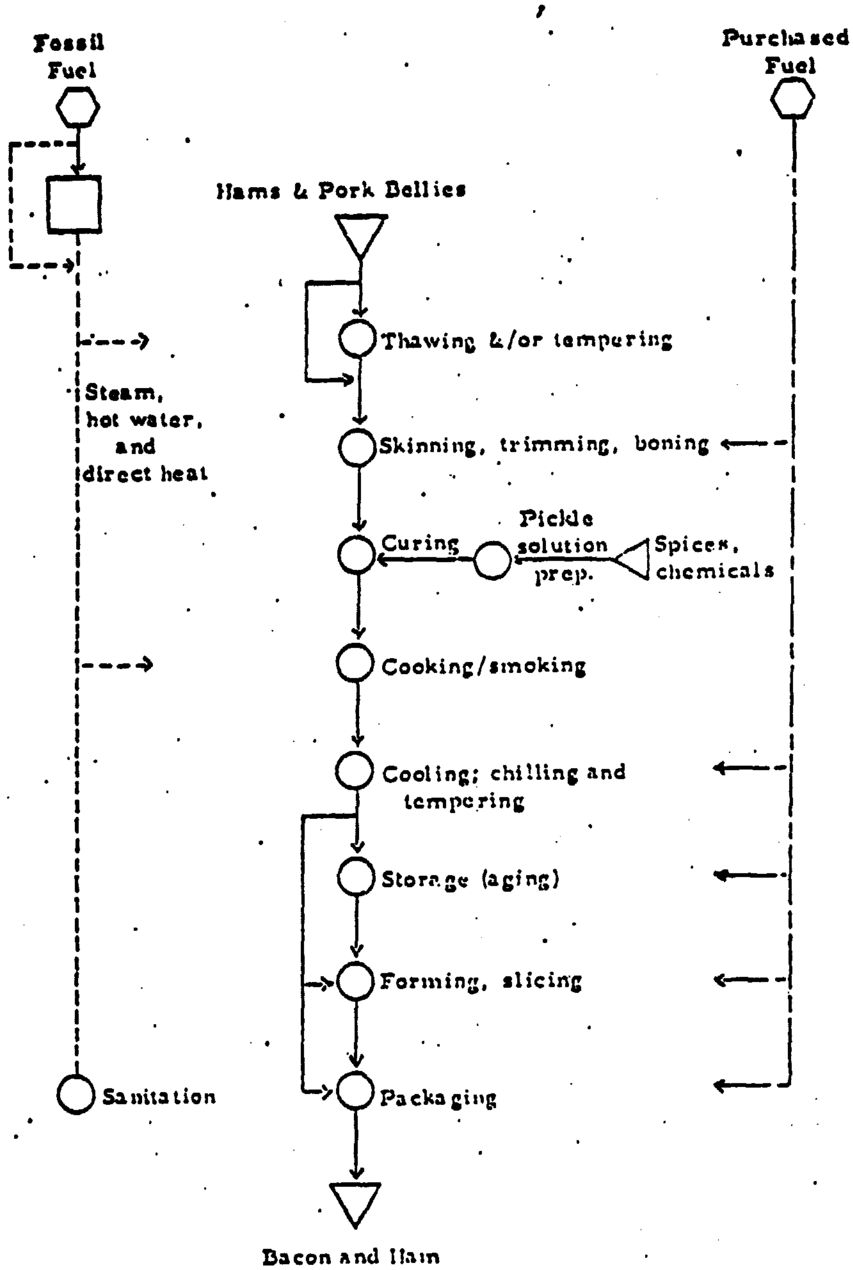
(Slaughtering Sector Only)



Source: Development Planning and Research Associates Inc., Industrial Energy Study of Selected Food Industries. Prepared for Federal Energy Administration, 1974 (NTIS PB 237316)

EXHIBIT 201-2

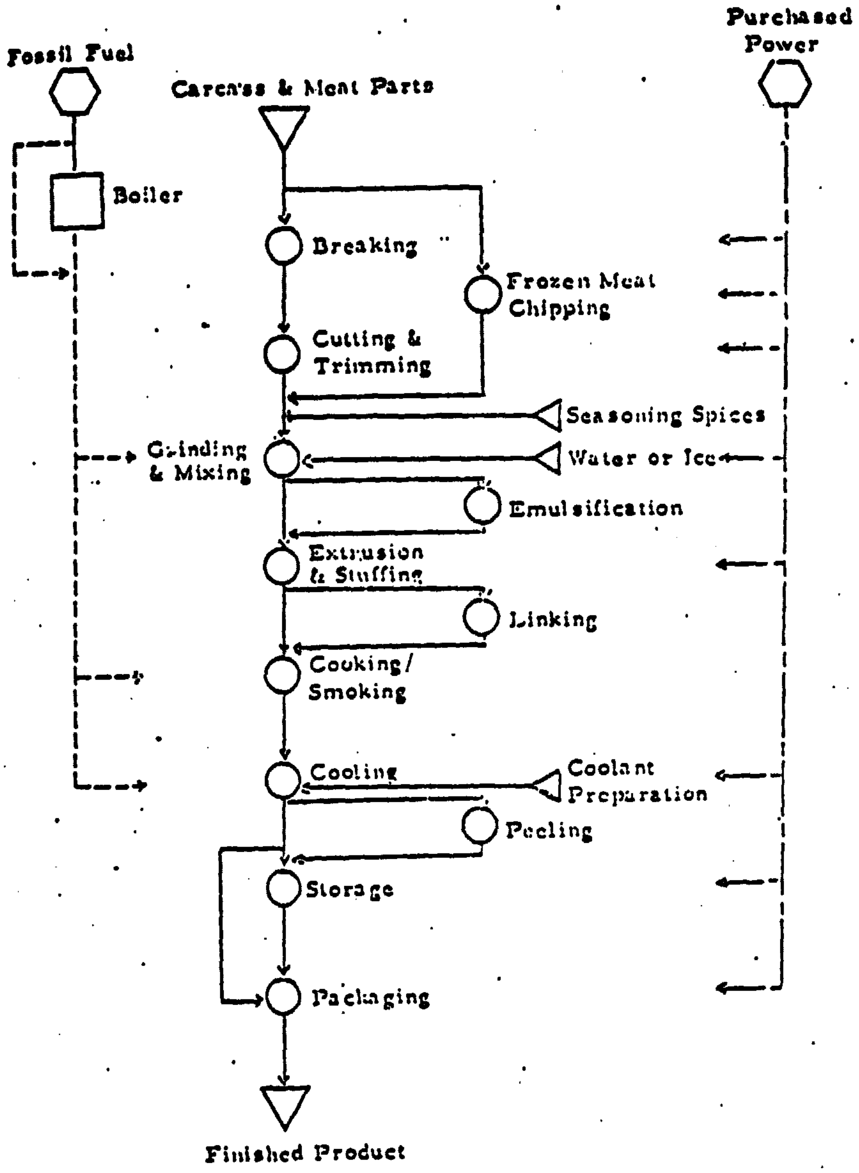
DIAGRAM OF MATERIAL AND ENERGY FLOWS FOR PROCESSING HAM, BACON AND PICNICS



Source: Development Planning and Research Associates Inc., Industrial Energy Study of Selected Food Industries. Prepared for Federal Energy Administration, 1974 (NTIS PB 237316)

EXHIBIT 201-3

DIAGRAM OF MATERIAL AND ENERGY FLOWS FOR SAUSAGE AND COMMINUTED MEAT PRODUCTS



Source: Development Planning and Research Associates Inc., Industrial Energy Study of Selected Food Industries. Prepared for Federal Energy Administration, 1974 (NTIS PB 237316)

EXHIBIT 201-4

DIAGRAM OF MATERIAL AND ENERGY FLOWS FOR CANNED MEAT PRODUCTS

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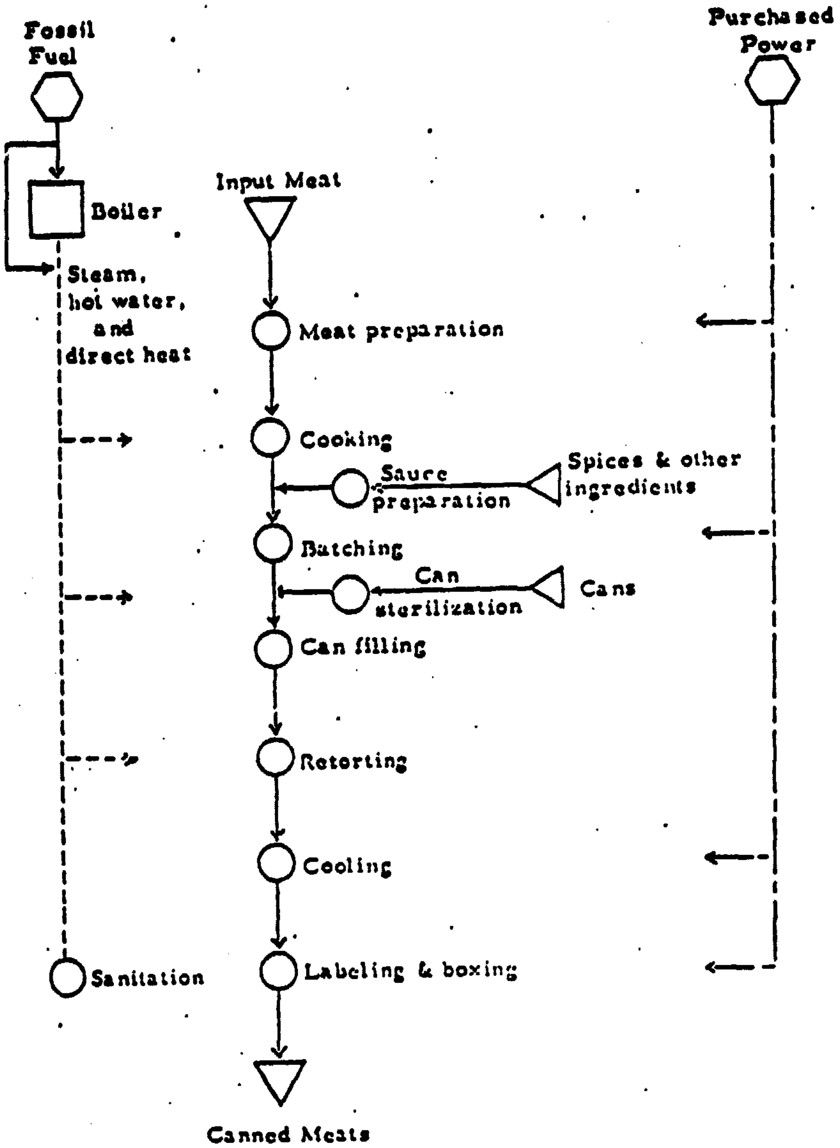

Source: Development Planning and Reserach Associates Inc., Industrial Energy Study of Selected Food Industries. Prepared for Federal Energy Administration, 1974 (NTIS PB 237316)

EXHIBIT 201-5

ANNUAL NATIONAL DATA (1975), MEAT PACKING INDUSTRY

SIC	Product Production Million Ton	Total Energy Consumption Trillion Btu	Purchased Electricity Trillion Btu	Purchased Fuels Trillion Btu	Coal	Oil	Gas	Other	Total Energy Consumption for SIC Trillion Btu	Percent Total Energy Consumption Represented
2011	15.9	70.6	13.0	57.6	11.8	7.7	36.0	2.1[1]	70.6	100
2013	2.6	16.0	4.6	11.4	-	4.4	5.6	1.4	16.0	100

* Purchased electricity converted to Btu at 3413 Btu/kWh

1 Estimated

EXHIBIT 201-6

Number of Federally Inspected Plants as of March 31, 1976, by Region

Region	Slaughter Only	Process Only	Slaughter & Process	Total
North Atlantic	207	1706	295	2228
North Central	86	973	434	1493
South Atlantic	21	316	42	377
South Central	30	519	271	820
Mountain	13	121	117	351
Pacific	42	901	163	1106
	397	4656	1322	6375

Source: Meatfacts 1977 (American Meat Institute, Washington, D.C. 1977).

EXHIBIT 201-7

Federally Inspected Slaughtering Plants

by Specie and Size, 1976

Size Thousand Animals Slaughtered	Cattle	Calves	Sheep & Lamb	Hogs
Under 100			639	
Under 500		693		
100-999			159	
500-4,999		106		
Under 1,000	809			
1,000 and over			80	
5,000 and over		98		
1,000-9,999	437			186
10,000-49,999	202			
10,000-99,999				84
50,000 and over	217			
100,000 and over				116
TOTAL	1665	897	878	1322

Source: Meatfacts 1977 (American Meat Institute, Washington, D.C. 1977) 12-13

EXHIBIT 201-8

U.S. Meat Production*

(Annual Million Pounds)

	Beef	Veal	Lamb	Pork	Totals
1960	14,753	1,109	768	11,607	28,237
1962	15,324	1,015	808	11,827	28,974
1964	18,456	1,013	715	12,513	32,697
1966	19,726	910	650	11,339	35,280
1968	20,880	734	602	13,064	32,625
1970	21,685	588	551	13,438	36,262
1972	22,419	459	543	13,640	37,061
1974	23,138	486	465	13,805	37,894
1975	23,976	873	410	11,503	36,762
1976	25,969	853	371	12,415	39,608

Source: Meatfacts 1977 (American Meat Institute, Washington, D.C., 1977) 16-17.

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* U.S. Department of Agriculture and U.S. Department of Commerce report meat production for SIC 2011 and SIC 2013 on a different basis. USDA figures are generally about 17% higher than DOE data.

EXHIBIT 201-9

ENERGY CONSUMPTION PER UNIT OUTPUT* IN MEAT PACKING/PROCESSING

Electricity Million Btu Per Ton	Hot Water Million Btu Per Ton	Steam Million Btu/Ton to 300°F	Steam Million Btu/Ton 300-500°F	Steam Million Btu/Ton Over 500°F	Direct Fuel*** Million Btu Per Ton	Exhaust Stream Temperature °F	Exhaust Stream Energy Million Bt Per Unit
0.822	1.47****	0.99	-	-	0.17	-	-

* Unit output denotes one ton meat product.

** For an Integrated Plant

*** Assuming 3413 Btu/Kwh

**** 1.37 x 10^6 Btu/Ton generated from steam, remainder generated from waste heat

EXHIBIT 201-10

ELECTRIC ENERGY CONSUMPTION IN THE FIVE REPRESENTATIVE MEAT PACKING PLANTS

(Thousand KWH per year)	PLANT A	PLANT B	PLANT C	PLANT D	PLANT E
Total Electric Energy Consumption	2507	7142[a]	834	303	23920
Refrigeration	1254		417	163	5750
Rendering	390		-	-	(b)
Lighting	276		94	36	4500
Maintenance Shop	251		-	-	(b)
Kill Room/Slaughterhouse	100		28	-	(a)
Processing Plant	-		150	42	8560
Cured Meat	-		145	-	-
Miscellaneous	326			62	5170
Average Demand (KW)	600	1200	180	NA	3000
Load Factor (%)	79	NA	NA	NA	93

Notes:
(a) Breakdown not given
(b) Included in miscellaneous uses
NA=Not Available

SOURCE: Johns-Manville Corporation, A Study of Energy Conservation Potential in the Meat Packing Industry, Prepared for the Federal Energy Administration, May 1976.

EXHIBIT 201-11

STEAM CONSUMPTION IN THE FIVE REPRESENTATIVE MEAT PACKING PLANTS

	PLANT A[a]	PLANT B[b]	PLANT C[a]	PLANT D[d]	PLANT E[b]
Total Steam Production	16200	147500	935		336400
Hot Water Generator/Heaters	8330	32000	-	-	180000
Space Heating	-	6000	-		13000
Cookers/Rendering	5950	57500	25	-	83000
Open Tallow Cooker Tank	600	-	-	-	-
Knife Sterilizers	120	8000	250[c]	-	2500
Unit Heaters	420	-	20	-	-
Steam Tracing	120	-	-	-	26000
Power Turbines	-	-	-	-	-
Hog Scalding	-	4000	-	-	15000
Smokehouses	-	-	630	-	-
Process Ovens	-	-	-	-	10000
Blowdown & Losses	420	31000	10		-
Miscellaneous	240	5000	-	-	6000
Steam Condition	NA	NA	NA	NA	300 PSIG, 580°F 110 PSIG SAT 70 PSIG SAT

Notes:
(a) Thousand BTU per hour
(b) Million BTU per year
(c) Also includes scalding tank and hot water for washup.
(d) Not given
NA= Not Available

SOURCE: Johns-Manville Corporation, A Study of Energy Conservation Potential in the Meat Packing Industry, Prepared for the Federal Energy Administration, May 1976.

EXHIBIT 201-12

NATURAL GAS USE IN THE FIVE REPRESENTATIVE MEAT PACKING PLANTS

All figures million BTU/year.

	PLANT A	PLANT B	PLANT C	PLANT D[b]	PLANT E
Total Gas Consumed	38964	181510	4630[a]	787	479720
Boiler/Hot Water Heaters	38542	173134	-	200	434060
Space Heating	422	-	-	187	-
Hog Singer	-	2976	-	-	7000
Unit Heaters	-	400	-	-	-
Lard Rendering	-	-	-	40	-
Processing Plant	-	-	680	-	12000
Slaughterhouse	-	-	574	-	-
Cured Meat/Smokehouse	-	-	3369	360	-
Miscellaneous Uses	-	-	-	-	660
Gas Engine	-	-	-	-	26000

Notes:

(a) Processing plant gas usage includes 3 space heaters, hot water heater, welfare room furnace, office and retail store furnace. Slaughter house gas usage includes 7.5 HP boiler, 2 space heaters, hot water heater. Cured meat gas usage includes 20 HP boiler, space heater, hot water heater, office furnace and drying room furnace.

(b) Plant "D" uses propane instead of natural gas.

SOURCE: Johns-Manville Corporation, A Study of Energy Conservation Potential in the Meat Packing Industry, Prepared for the Federal Energy Administration, May 1976.

EXHIBIT 201-13

PER CAPITA CONSUMPTION OF U.S. MEAT

(pounds per person)

Year	Beef	Veal	Lamb	Pork	Total
1960	85.1	6.1	4.8	64.9	160.9
1962	88.9	5.5	5.2	63.5	163.1
1964	99.9	5.2	4.2	65.4	174.7
1966	104.2	4.6	4.0	58.1	170.9
1968	109.7	3.6	3.7	66.2	183.2
1970	113.7	2.9	3.3	66.3	186.3
1972	116.1	2.2	3.3	67.4	189.0
1974	116.8	2.3	2.3	66.6	188.0
1975	120.1	4.2	2.0	54.8	181.1
1976	128.8	4.0	1.9	58.0	192.7

Source: Meatfacts 1977 (American Meat Institute, Washington, D.C. 1977) 16-17

EXHIBIT 201-14

MEAT PACKING (SIC 2011) AND PROCESSING (SIC 2013)
PRODUCTION STATISTICS AND FORECASTS
TO 1985 AND 2000

(Million Tons Product)

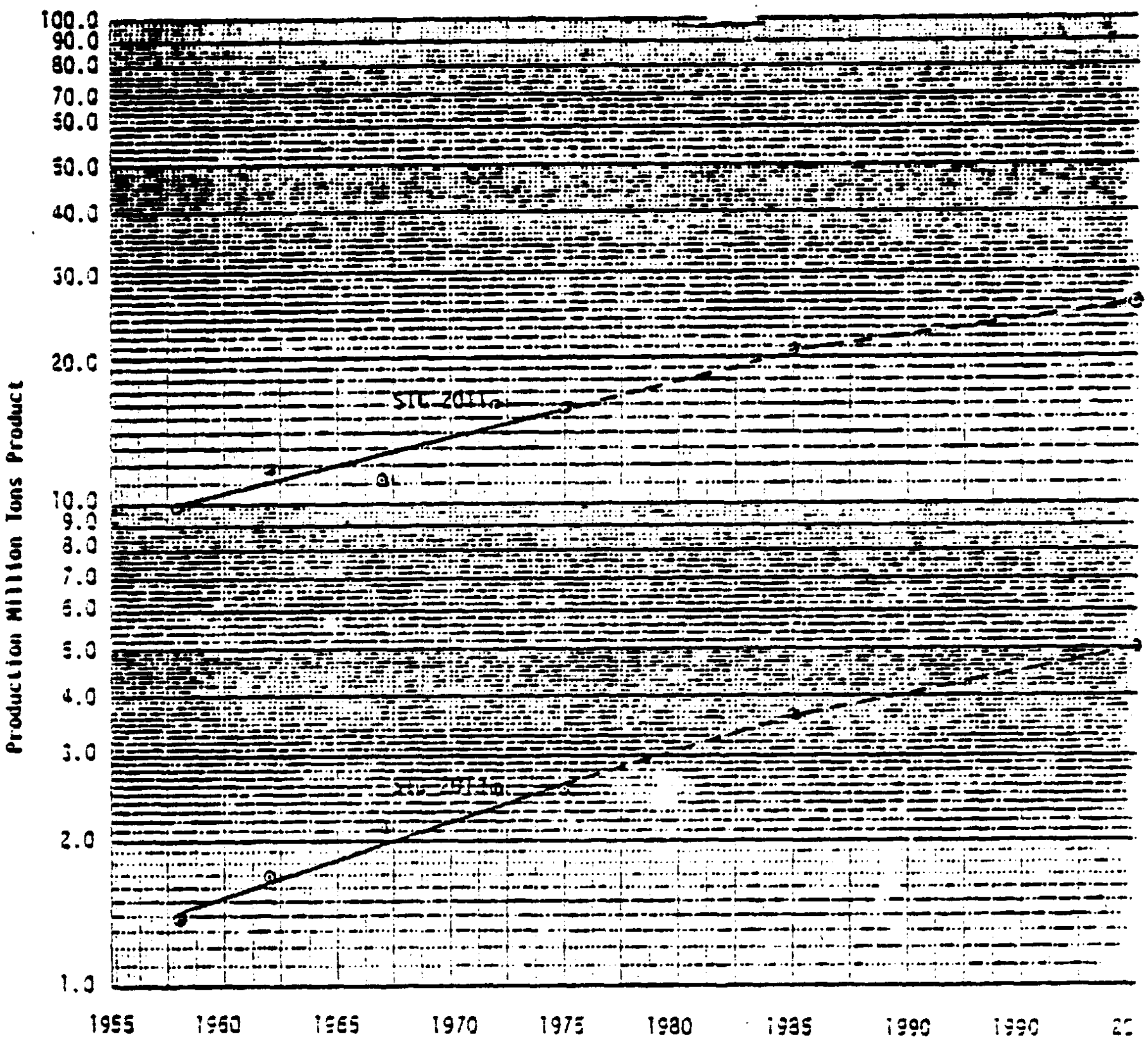

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EXHIBIT 201-15

ESTIMATED ANNUAL ENERGY CONSUMPTION
IN MEAT PACKING AND PROCESSING
(Trillion Btu)

	1975(1)		1985(3)		2000(4)	
	SIC 2011	SIC 2013	SIC 2011	SIC 2013	SIC 2011	SIC 2013
Purchased Fuel	57.6	11.4	62.8	13.5	73.9	17.3
Purchased Electricity(2)	13.0	4.6	14.2	5.4	16.7	6.9

(1) From Exhibit 201-10

(2) Electricity converted to Btu's at 3413 Btu/kWh

(3) Data for 1985 is based on the following assumption:

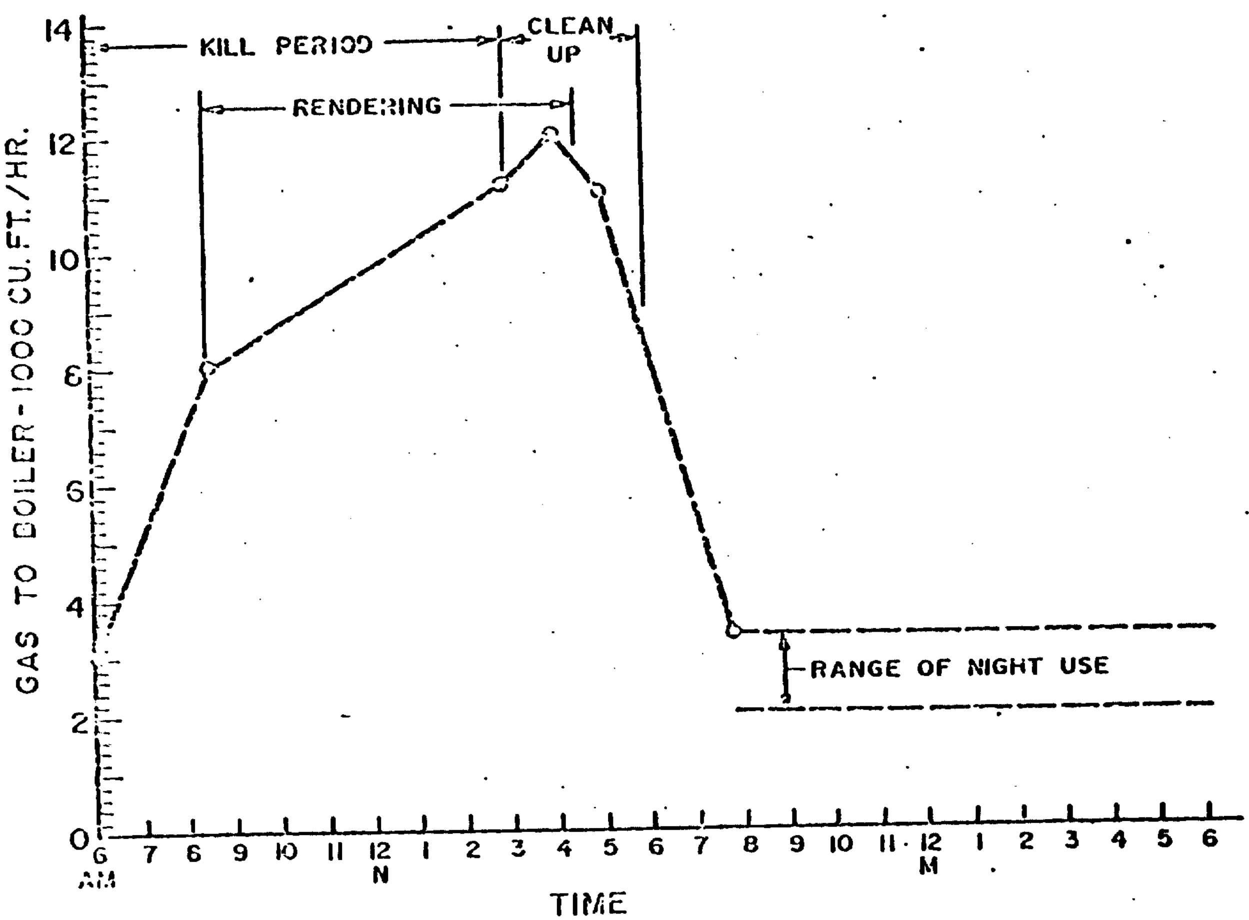
- Annual growth rates in production of 276 percent/year for SIC 2011 and 3.74 percent/year for SIC 2013 from 1975 to 1985 with a decrease of 17% in energy requirements per unit of production from 1975. Refer to Section 4.1 for forecast production.

(4) Data for 2000 is based on the following assumption:

- Annual growth rates in production of 1.4 percent/year for SIC 2011 and 2.0 percent/year for SIC 2013 from 1985 to 2000. During the same time period an additional 5% improvement in energy requirements as compared to 1975 is achieved.

EXHIBIT 201-16

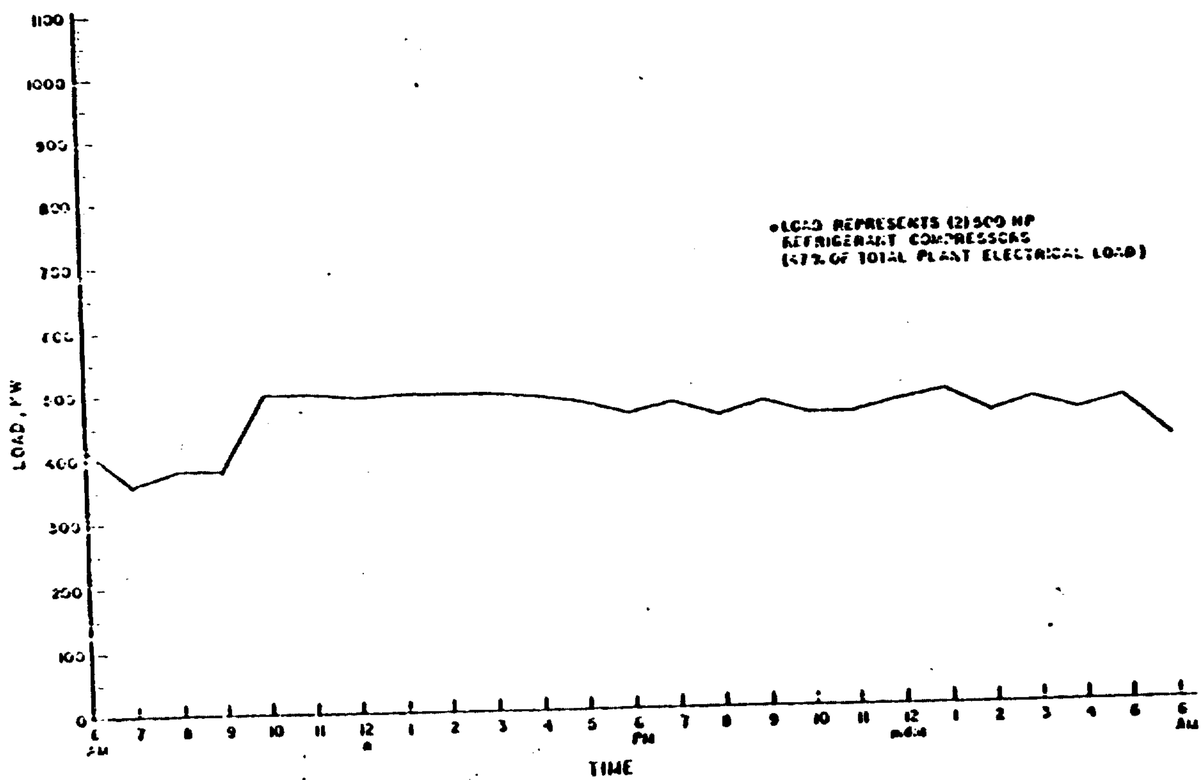
NATURAL GAS INPUT TO BOILER FOR MEAT PACKING PLANT "A"



SOURCE: Johns-Manville Corporation, A Study of Energy Conservation Potential in the Meat Packing Industry, Prepared for the Federal Energy Administration, May 1976.

EXHIBIT 201-17

ELECTRIC LOAD CURVE FOR PLANT "B" REFRIGERATION



SOURCE: Johns Manville Corporation "A Study of Energy Conservation Potential in the Meat Packing Industry", prepared for the FEA, May 1976.

EXHIBIT 201-18

ENERGY LOADS FOR MEAT PACKING PLANTS

Plant	Approx. No. of Employees	Days of Operation	Process	Ratio of BTU Elec. Energy/BTU Therm. Energy	Actual Plant Steam Consumption (MBTU/hour)	Average Electric Power Demand (KW)
"A" (Med. Size Plant)	100	5 day 1 shift	Cattle slaughter 500-550/day	0.239	16200	600
"B" (Med. Size Plant)	300	5 day 1 shift	Hog slaughter	0.166	16838	1200
"C" (Small Size Plant)	35	5 day 1 shift	Slaughter 25-40 cattle/week 20-30 hogs/week and processing	0.7[illegible]9	935	180
"E" (Large Size Plant)	1000	5 day 3 shift	Slaughter 3500-4000 hogs/day 400-500 cattle/day and processing	0.228	38402	3500

EXHIBIT 201-19

ELECTRIC ENERGY USE AT PLANT "E"

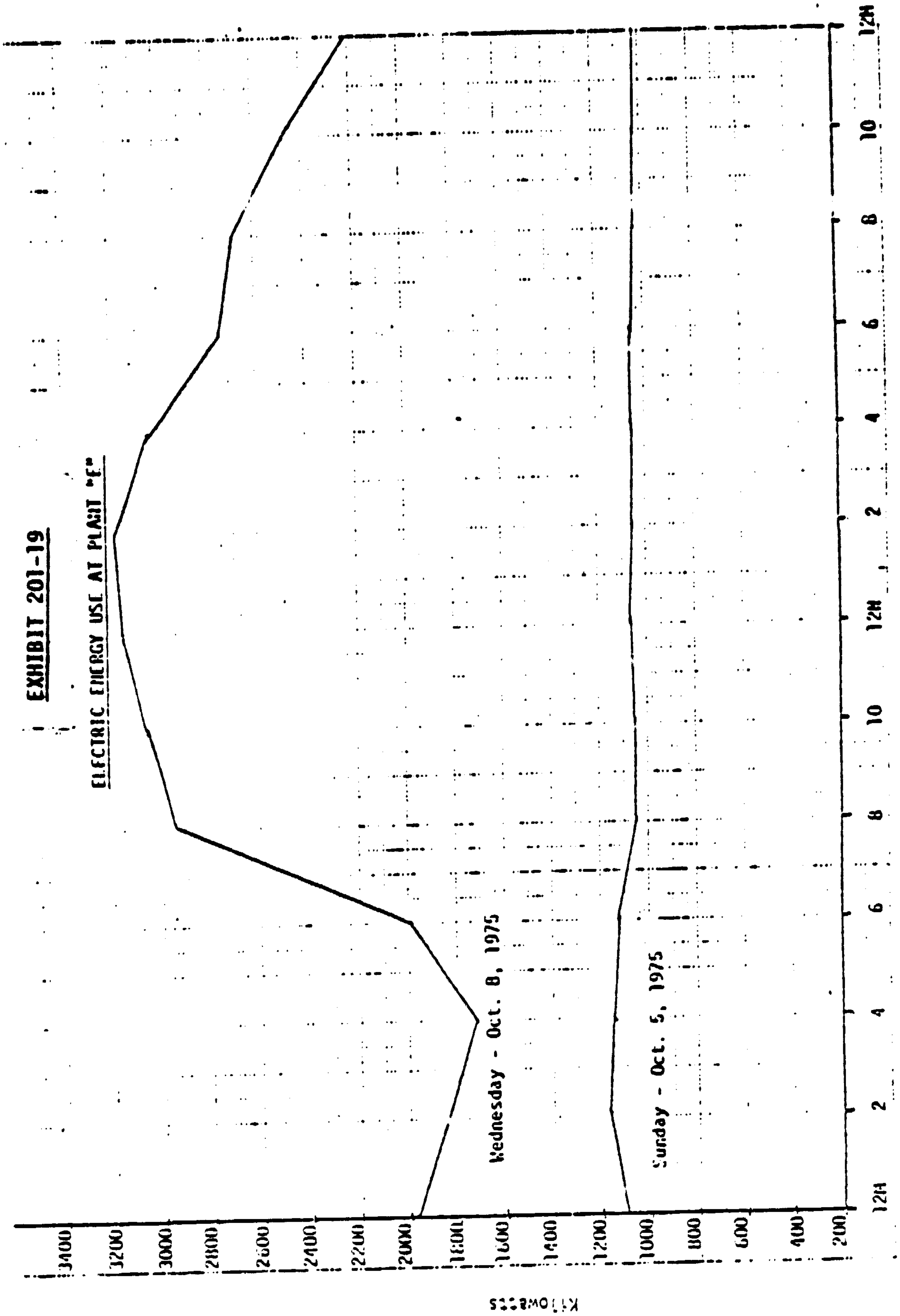


EXHIBIT 201-20

STEAM USE AT PLANT "E"

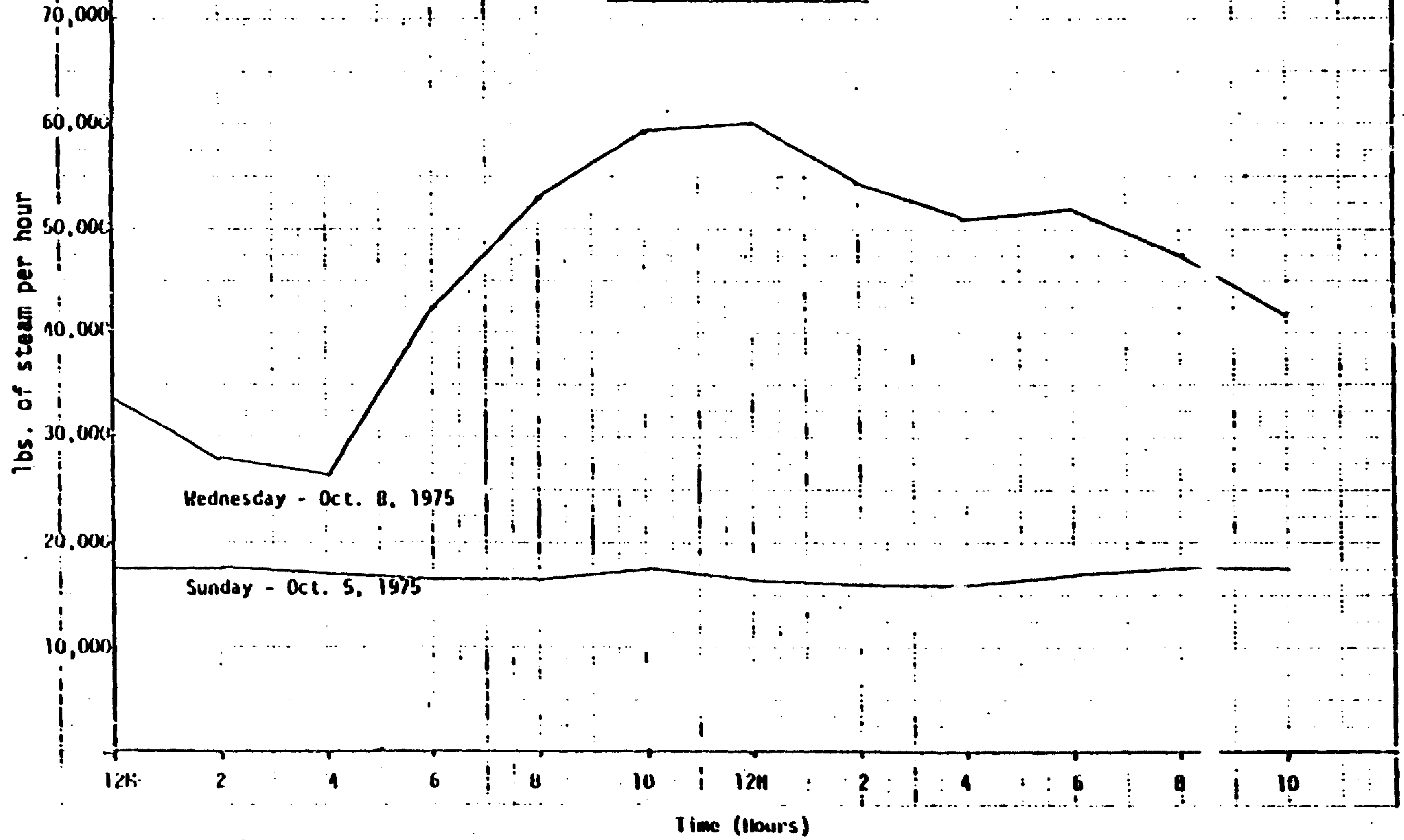


EXHIBIT 201-21

HOT WATER USE IN PLANT "L"

110° Water (Gallons)

Period	Sunday 10/5/75	Wednesday 10/8/75	Sunday 1/4/76	Wednesday 1/7/76	Sunday 4/4/76	Wednesday 4/7/76	Sunday 7/25/76	Wednesday 7/28/76
10:00 pm to 6:00 am	2,016	38,015	16,344	60,552	2,160	47,636	2,232	67,536
6:00 am to 2:00 pm	864	291,600	17,280	274,032	360	275,040	1,152	270,344
2:00 pm to 10:00 pm	936	184,968	11,736	70,992	1,152	154,424	1,152	151,344
24 hour Total flow	38,161	514,584	45,360	405,576	3,672	975,100	4,536	489,168

160° Water (Gallons)

Period	Sunday 10/5/75	Wednesday 10/8/75	Sunday 1/4/76	Wednesday 1/7/76	Sunday 4/4/76	Wednesday 4/7/76	Sunday 7/25/76	Wednesday 7/28/76
10:00 pm to 6:00 am	390	53,460	150	74,790	-	86,100	-	70,500
6:00 am to 2:00 pm	-	75,630	-	81,030	-	168,390	-	63,630
2:00 pm to 10:00 pm	-	106,830	-	77,580	-	112,710	-	112,680
24 hour Total flow	390	235,920	150	233,400	-	367,200	-	245,810

EXHIBIT 201-22

MEAT PACKING PLANT FACTORS

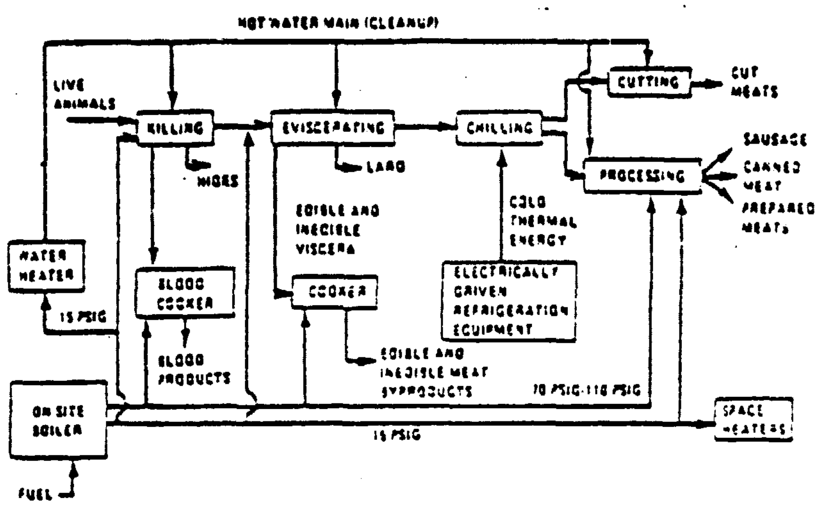
TYPICAL PLANT CAPACITY TONS/HOUR	PLANT SIZE RANGE TONS/HOUR	ELECTRIC LOAD FACTOR	THERMAL ELECTRICAL COINCIDENCE FACTOR	PROJECTED APPLICABILITY TO 2000
40	1-53	0.86**	0.3	*

* The trend in the industry is towards longer, integrated plants, with the "typical" plant approaching 40-50 tons/hour. As larger integrated plants come on-stream, multiple shifts will be used, resulting in a more even demand for energy and increased electrical load factors. There are likely to be less seasonal variations for thermal energy requirements in comparison to electrical requirements thus increasing the coincidence factor.

** May be as low as 0.79 for a medium plant such as Plant A or as high as 0.93 for a large integrated plant such as Plant E.

EXHIBIT 201-23

PROCESS AND PLANT SCHEMATIC - MEATPACKING PLANT



THE BAKING INDUSTRY: BREAD, CAKES AND RELATED PRODUCTS

1.0 Process Identification

This section identifies and specifically defines the industry, and provides a brief description of the current production processes employed.

1.1 SIC Classification

The production of bread, cakes and related products is classified under SIC code 2051, which covers "establishments primarily engaged in manufacturing bread, cakes, and other perishable bakery products." Establishments which are primarily engaged in producing dry bakery products such as cookies and crackers are classified under SIC 2052, and retail bakeries are classified under SIC 5462; these latter two industries are not considered herein.

1.2 Process Description

The sequence of operations for the manufacture of baked goods is the same for all baked goods. The raw materials are measured, mixed and fermented (for yeast containing products). The mix is then subdivided, shaped and placed in pans, whereupon the dough undergoes proofing (for yeast-containing products), baking, finishing and wrapping.

The largest volume products under SIC 2051 are bread and bread rolls. Approximately 80% of the output (by weight) of SIC 2051 consists of bread and rolls with the other 20% distributed between cakes, pies, doughnuts and pastries.

There are three basic methods of breadmaking. These are the sponge-dough, straight-dough and continuous-mix methods. In the sponge-dough method a portion of the ingredients are mixed to a stiff dough called sponge. Once the sponge has been allowed to ferment for about

five hours, the remaining ingredients are blended in to make the final dough. The dough is rested, divided into pieces and rested again. The dough is moulded, placed in a pan and sent to the proofer (105-115°F humid atmosphere) for about an hour where the dough leavens. Following proofing the dough is baked at about 400°F for eighteen to twenty five minutes. The finished bread is allowed to cool and is sliced and packaged.

The straight-dough method is a one step procedure in which all the ingredients are blended together to produce a smooth dough. Each batch may weigh from 500 to 2,000 lbs. The dough is fermented for two to four hours in a trough, from which point the dough is processed in the same manner as is the final dough from the sponge-dough process.

The continuous-mix method uses a slurry of water, sugar, yeast, buffer, and on occasions some flour. This slurry can be readily pumped and is called the brew. After the brew is fermented for several hours and cooled to 40°F, the balance of the flour and other ingredients are continuously blended in. The dough is next forced through a pressurized mixing chamber. After being extruded from the mixing chamber, the dough is cut off into pieces which are placed into pans, from which point the dough is processed in the same manner as is the final dough in pans from the sponge-dough process. Exhibit 2051-1 illustrates in schematic form the steps involved in the sponge dough and continuous mix processes, as well as indicating flows of materials and energy.

Hot dog and hamburger rolls are produced from bread type sponge doughs that generally contain increased amounts of sugar and fat.

Cakes are manufactured using a continuous mix process. The blended ingredients are pumped to a continuous aerating unit in which the air pressure and mix temperature control the batter density. The batter is

delivered into oiled pans and baked at about 350oF. The baking time depends on the type and size of the cake. After the cakes are cooled they are iced, filled and packaged. Doughnuts are not baked but are deep fried in fat. Exhibit 2051-2 schematically illustrates these steps along with major material and energy flows for a typical cake plant.

Danish pastry, sweet rolls, and coffee cakes (sweet yeast-raised products) are prepared by the sponge-dough procedure.

2.0 National Data

The annual national data presented in this section are summarized in Exhibit 2051-3. The derivation and significance of the production and energy consumption data are discussed in the following sub-sections.

2.1 Capacity and Production Data

There are more than 3,300 baking facilities under SIC 2051 employing more than 194,000 employees. The value of shipments in 1972 was $6.2 billion.[1]

Production in this industry was about 20.14 billion pounds in 1975, up 4% from the 1972 figure. Production in 1977 is estimated to have been about 19.95 billion pounds, or 1% below the 1975 production figures, according to the American Bakers Association.

The bread and rolls segment of SIC 2051 accounted for 82% of the production of this industry in 1972. Cakes, pies, doughnuts and other pastries accounted for the other 18% of production.

There are baking facilities located in each of the 50 states and the District of Columbia. The baking industry, however, is distributed non-uniformly throughout the United States. The top six baking states (California, Illinois, New Jersey, New York, Ohio and Pennsylvania), account for close to 50% of all U.S. production.

Plant sizes vary widely in the baking industry. Small plants produce as little as 100,000-300,000 pounds per year, while large facilities produce as much as 30-50 million pounds per year. Plants with less than 20 employees accounted for 60% of the facilities in 1972, while plants with more than 100 employees produced 81% of the goods,

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1. U.S. Department of Commerce, Census of Manufactures 1972, Industry Series MC 72 (2)-20E, January 1975.

although only accounting for 18% of the facilities. Since they produce most of the industry output, the larger plants are usually considered more typical of the industry, bearing in mind that no one plant can be truly considered typical due to large variations in product mix.

2.2 Annual Energy Consumption

The U.S. Census Bureau reports the following consumption of energy in 1975 by SIC code 2051.[1]

1975 ENERGY CONSUMPTION, SIC 2051

Energy Source	Consumption
Fuel Oil	3.86×10^{12} Btu
Natural Gas	20.79×10^{12} Btu
Other Fuels*	9.15×10^{12} Btu
Purchased Electricity	2198.7×10^{6} kWh

* Includes coal, coke and other fuels such as propane.

Bakery products are the only products of SIC 2051 (see Section 1.1). Therefore the energy consumed by the perishable bakery products industry should correspond to the energy figures reported for SIC 2051 in the Annual Survey of Manufactures.

The use of coal is very limited in this industry (about 0.05×10^{12} Btu/yr). Coke and breeze use is essentially zero. This industry does use considerable quantities of propane, which probably accounts for most of the other fuels use shown in the above table. No significant quantities of electricity are generated onsite in the baking industry.

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1 U.S. Department of Commerce, "Annual Survey of Manufactures", Fuels and Electric Energy Consumed, 1975 Edition.

3.0 PROCESS ENERGY REQUIREMENTS

The sub-sections which follow describe in depth the energy consumed per unit of production in the manufacture of bakery products, as well as providing detail on the type of energy required. A summary of the energy requirements per unit output appears in Exhibit 2051-4.

3.1 Unit Energy Consumption Data

The baking industry is very dependent on the use of natural gas to fire ovens. The vast majority of ovens (88% in 1975[1]) are directly fired with natural gas. It is not possible to convert these ovens so that they may be indirectly fired, however when faced with curtailment in their natural gas supplies some bakeries have been able to use propane. Ovens cannot be directly fired with oil or coal, due to possible contamination of the product, although a few ovens use electric energy, primarily in the Northwest U.S.

Natural gas has a high hydrogen content, therefore the products of combustion are high in water content (present as superheated steam). This superheated steam imparts a certain desirable taste and appearance to the baked goods. The effect of the superheated steam on the baked goods is superior to that obtained with indirectly heating the oven and injecting steam.

Supplementary steam is injected into the ovens when dense breads (such as rye or Vienna) or glazed pastries are being baked.

The perishable baked goods industry may be divided into two major sub-groups. Bread and rolls comprise one group, while cakes, pies and

1 Gordian Associates Inc., "Natural Gas Profile of the Baking Industry", New York, October 1975

doughnuts comprise the other. It is usual for a large baking facility to produce several products within one of these groups, but not within the other. Therefore the unit energy consumption figures, as presented in Exhibit 2051-4, are shown separately for each product group.

Natural gas and propane supply the direct fuel which is the largest use of energy in baking (about 55% of the total Btu's). Steam, electrical energy and hot water supply the rest of the energy needs.

Energy requirements per pound of baked goods are shown in Exhibit 2051-4. Total requirements are 1355 Btu/lb for bread and rolls, and 1283 Btu/lb for cakes, pies and doughnuts.

3.2 Details of Electricity Consumption

Baking plants generally operate 5 days per week, 2 shifts per day. Electrical energy is required 24 hours per day, 7 days per week since, during non-production periods (nights and clean-up days), it is required for refrigeration and lighting purposes. The load factor is approximately 0.56 for this industry as a whole.

Baking plants require electrical energy for lighting, refrigeration, air compressors, conveyors and mixers. Electricity is supplied at 120 volts, 60 Hz for lighting, and at 240,440 and 660 volts, 60 Hz for general plant use. Baking plants generally use 3 phase 4 wire electric power. Direct current power is not ordinarily used.

The monthly demand for electrical energy tends to be slightly higher in the summer months due primarily to increased refrigeration loads, and air conditioning use for offices. Refrigeration and air conditioning, on average, account for only about 13% of the electrical energy in a typical plant. The largest use is for lighting, which

accounts for some 30% of total usage in a typical facility. A complete breakdown of electrical energy use appears in Exhibit 2051-6.

As stated previously, (see Section 3.1), a few baking plants, located primarily in the northwestern U.S., use electrical energy to heat their ovens. Steam must be injected to electrically heated ovens to obtain a satisfactory product. Less than 2% of the baking ovens are believed to be electrically heated. Some electrical energy is used on conventional ovens for drives, conveyors and in the agitation system, which is a fan-type device that circulates the air in the oven to obtain even heating.

3.3 Details of Thermal Energy Consumption

Large quantities of low pressure steam are used in baking plants. Steam is used for water heating, space heating, injection into ovens, and injection into proof boxes. The steam used in bread plants is usually around 10-15 psig, while cake plants generally use 30-40 psig steam.

The largest process use of steam is for injection into proof boxes. Proof boxes, where the dough leavens, are kept at 105-115°F and very humid.

Baking facilities use considerable quantities of hot water, primarily for clean-up purposes. The hot water temperature is generally 160-180°F. Hot water used to clean baking pans and other equipment which comes in contact with the food, must be at 180°F at the point of use, as required by Federal regulation.

Steam requirements vary from plant to plant. Plants producing glazed baked goods or dense breads, for example, require larger amounts of steam to be injected into the ovens. Steam use is generally higher during the winter months, when it is used to provide space heating.

This, of course, depends on the geographic location and specific layout of the plant.

Unit thermal energy requirements are presented in Exhibit 2051 - 4. Bread and rolls require 723 Btu of direct process fuel, 366 Btu of low pressure steam and 22 Btu of hot water for each pound produced. Cakes, pies, doughnuts and other pastries require 571 Btu of process fuel, 468 Btu of low pressure steam and 9 Btu of hot water per pound of output.

The steam load is decreased during non-production periods. Heating and hot water use (about 57% of the thermal energy) is about the same in production and non-production periods. Steam use in ovens, fermentation and proof boxes is discontinued during non-production periods.

4.0 ANTICIPATED TRENDS

This section discusses the trends which are likely to occur in the industry thorugh the year 2000. The major emphasis is on three areas: production, technology, and energy consumption.

4.1 Product Growth Trends

Bread and other baked goods are staples of the American diet. Products of this industry are as important today as they were 20 years ago, and will be just as important in the year 2000.

The production of bread and other baked goods in the future will be influenced by population. It is expected that the rate of growth in the production of perishable baked goods in the U.S. will be approximately the same as the rate of growth of U.S. population in the period between the present and the year 2000. Per capita consumption of baked goods under SIC 2051 was 93 lbs in 1972.[1]

The likely future production of goods under SIC 2051 can be estimated by applying the 1972 U.S. per capita consumption to the population projections of the U.S. of the Census. The results of the above calculations are presented below:

PROJECTED PRODUCTION OF BAKED GOODS

Year	Population[2] (Million)	Expected Production (Billions of Pounds)
1980	222.159	20.6
1985	232.880	21.7
1990	243.513	22.6
2000	260.378	24.2

1 Derived from: U.S. Bureau of Census "1972 Census of Manufactures, Industry Series MC72 (2)-20E", January 1975, and reference 2 below.

2 U.S. Bureau of the Census, "Statistical Abstract of the U.S., October 1977, page 6, Series II Projections.

Thus the production of goods under SIC 2051 will increase by about 25% by the year 2000. This is equivalent to a growth rate of about 0.8% per annum.

Exhibit 2051-5 presents a graphical representation of historical and projected production under SIC 2051 in the period 1967 to 2000. The 1985 projection compares favorably with the estimates in the "Targets" document of 20.8 billion pounds of production in 1980.[1]

It is probable that although the per capita consumption is expected to be stable, the mix of products consumed will change. For example, in the last five years there has been a trend toward the increasing consumption of "fast foods". This trend has resulted in the increased consumption of hamburger and hot dog rolls. Recently earth grain breads (whole wheat, high fiber) have increased in popularity.

4.2 Process Changes and Implementation

The basic process used in making baked goods is perhaps several thousand years old. Although there is considerable new technology used in plants constructed within the last 10 years, including electrically driven ovens and mechanical conveying and packaging of products, the basic process has not been significantly changed.

Two factors will serve to limit process changes from being implemented in the near future. Firstly very few new facilities are scheduled for construction in the next 5 to 10 years. Older, small and outdated facilities have been shut down, and newer plants have been able to make up for lost production. Secondly, aside from increased mechanization, and the addition of energy saving devices, no really new processes for making bread have been discovered.

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1. Development Planning and Research Associates Inc., "Energy Efficiency Improvement Targets - Food and Kindred Products Industry", June 30, 1972, p. 10-12.

Several energy saving devices will be implemented in this industry. The installation of heat exchangers to recover energy from oven exhaust for preheating boiler feed is expected to be technically feasible and economically viable. Boiler efficiencies will be improved by expenditures for heat exchangers and water treatment facilities to reduce scaling.

4.4 Trends in Energy Requirements

In deriving the FEA Industrial Energy conservation "target" for SIC 20, a component "target" for SIC 2051 was derived. The component "target" for perishable baked goods industry is a 19% reduction in unit energy consumption by 1980 relative to 1972 energy consumption levels.[1] Sensitivity analysis in that document indicates that the "target" is unlikely to vary by more than 1% of the 1972 unit energy consumption.

The energy saving measures which will contribute to the 19% reduction in unit energy consumption include: improved oven scheduling, use of heat exchangers, improved housekeeping, improved boiler operating procedures, and other measures such as reduced levels of lighting.

Exhibit 2051-6 illustrates how the target was derived from component energy use and expected savings data. Assuming that the 19% energy savings will be achieved in 1985 as compared to 1975 energy usage, the expected energy usage for 1985 can be estimated, taking into account the expected 1985 level of production. It is expected that an additional 10% savings in purchased fuels, and an additional 5% savings in purchased electricity can be achieved by 2000. Since this industry has traditionally achieved a rather modest margin, future energy savings are likely to come from low cost measures such as increased housekeeping and better scheduling. The estimated energy consumption for 1985 and 2000 are presented in Exhibit 2051-7.

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1. Development Planning and Research Associates Inc., "Energy Efficiency Improvement Targets - Food and Kindred Products Industry", June 30, 1976.

5.0 PLANT SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements, including indications of load profiles and reliability considerations. Several plant factors are summarized in Exhibit 2051-8.

5.1 Load Profiles

As mentioned previously in Section 3.2 of this report, baking plants typically operate 5 days per week, 2 shifts per day. Demand for electrical energy is reduced during non-production periods (nights and clean-up days). Exhibit 2051-9 illustrates the high and low electric demand periods for a typical bread and rolls bakery. From this Exhibit, the load factor is estimated to be 0.56. Similar load factors will be observed for sweet goods plants (cakes, pies and doughnuts), as they generally operate on a 5 day, 2 shift basis as well.

Steam is used 24 hours a day for space heating and hot water generation. During non-production periods steam use is reduced, as the steam for injection into ovens and proof boxes is eliminated. The production of baked goods require the simultaneous use of electrical and thermal energy, indicating a thermal-electric coincidence factor of 1.0. Both thermal and electrical energy are required during clean-up periods.

5.2 Energy Flow Schematic

A simplified energy flow schematic for the production of bread and rolls (82% of production under SIC 2051 in 1972) appears in Exhibit 2051-10. All energy requirements in Exhibit 2051-10 are in Btu per pound of finished product. Electrical energy was converted to Btu's using 3413 Btu/kWh.

5.3 State Conditions and Mass Flows

As previously stated in Section 3.3 of this report steam used in this industry is usually 10-15 psig in bread and rolls plants, and 30-40 psig in cake plants. Hot water used for cleaning baking pans and other equipment which comes in contact with the food, must be at 180°F at the point of use, as required by Federal regulation.

The following materials were consumed by SIC 2051 in producing 1 lb of product (average mix over the entire SIC code):

Material	Units per lb. of Product[1] (Pounds)
Wheat Flour	0.504
Prepared Flour Mixes	0.027
Sugar	0.078
Shortening	0.025
Lard	0.012
Margarine and Puff Paste	0.003
Nutrients	1.709 (Grams per million pounds)
Other Fats and Oils	0.008
Dried Milk	0.009
Frozen and Liquid Eggs	0.008

5.4 Reliability Considerations

Baking facilities are likely to accept any system where the outage rate is comparable to or exceeds commercial utility system standards. Since large modern ovens rely on electric drives to convey products thorugh the ovens, outages are likely to cause a loss of production. Materials undergoing processing during an extended power outage would be lost. These include dough baking in ovens, as well as dough undergoing fermentation and proofing, and an extended outage could allow materials in storage such as frozen eggs and butter to spoil. Damage to process equipment due to an outage would not be severe.

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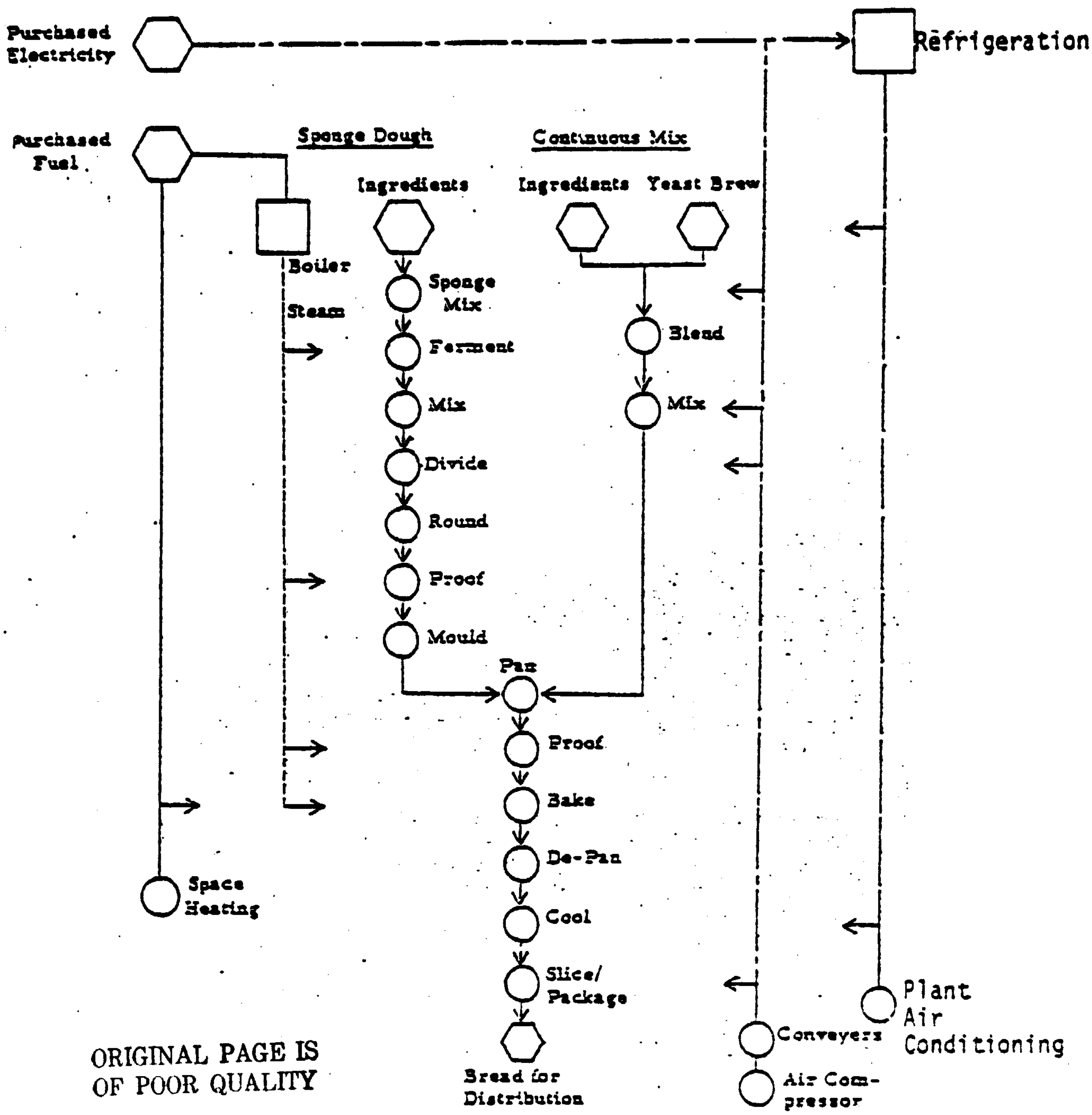
1. Derived from: U.S. Bureau of the Census, "1972 Census of Manufactures, Industry Series MC72 (2)-20E", January 1975.

EXHIBIT 2051-1

MATERIAL AND ENERGY FLOW FOR REPRESENTATIVE BREAD PLANTS SHOWING THE SPONGE DOUGH AND CONTINUOUS MIX PROCESSES

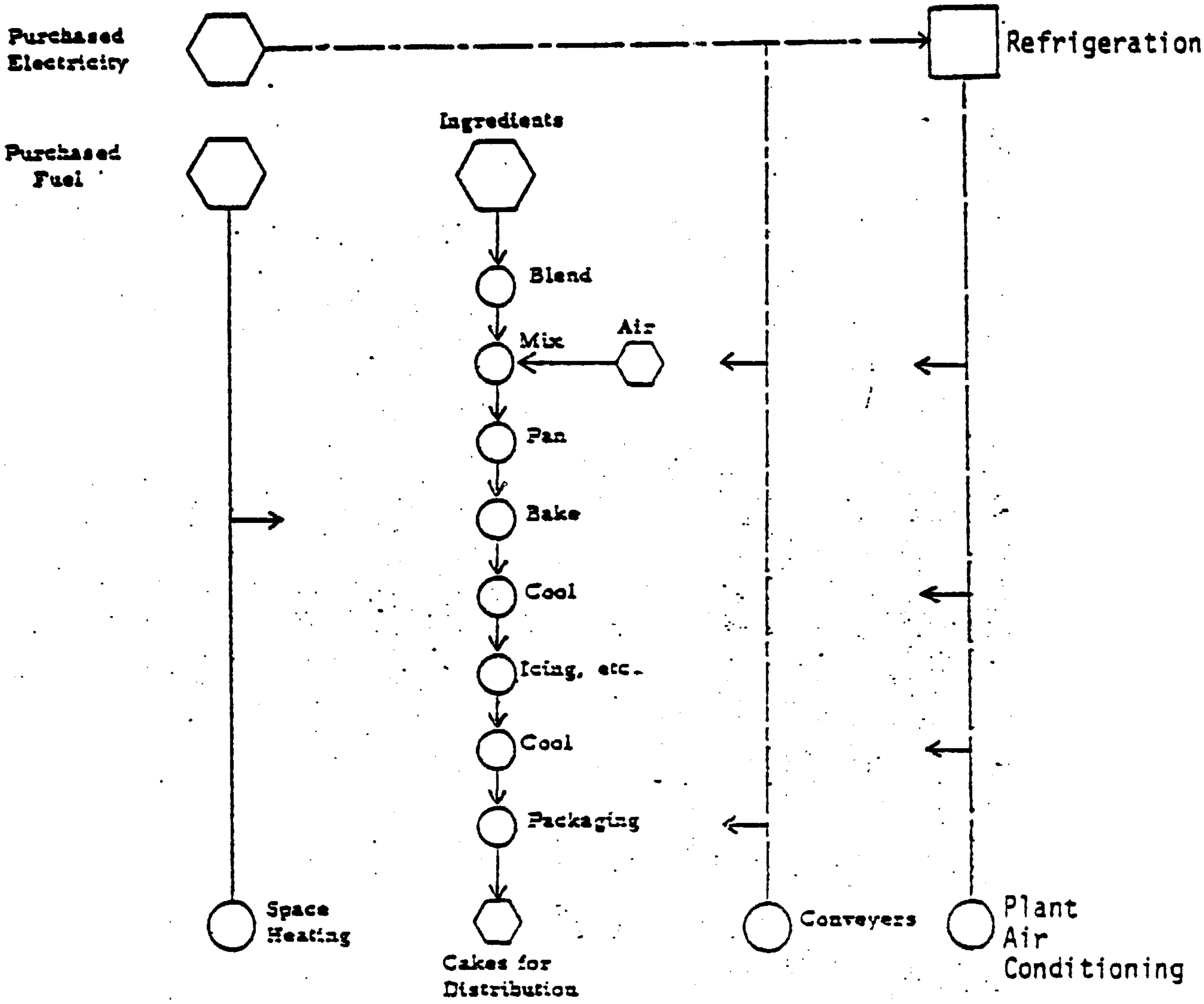


ORIGINAL PAGE IS OF POOR QUALITY

Source "Industrial Energy Study of Selected Food Industries", Federal Energy Office Contract No. 14-01-0001-1652, Development Planning and Research Associates Inc., July 1974.

EXHIBIT 2051-2

MATERIAL AND ENERGY FLOW FOR A REPRESENTATIVE CAKE PLANT USING THE CONTINUOUS MIX PROCESS



Source: "Industrial Energy Study of Selected Food Industries", Federal Energy Office Contract No. 14-01-0001-1652, Development Planning and Research Associates Inc., July 1974.

EXHIBIT 2051-3

ANNUAL NATIONAL DATA (1975), BREAD, CAKES, AND RELATED PRODUCTS

Product Production Million Ton	Total Energy Consumption Trillion Btu	Purchased Electricity Trillion Btu	Purchased Fuels Trillion Btu	Coal	Oil	Gas	Other	Total Energy Consumption for SIC Trillion Btu	Percent Total Energy Consumption Represented
10.07**	41.30*	7.50*	33.80	***	3.86	20.79	9.15****	41.30	100

* Purchased electricity converted to Btu at 3413 Btu/KWh.

** Based on the Production Index provided by the American Bakers Association and the 1972 Census of Manufactures.

*** Withheld by the Census Bureau to avoid disclosure (was about 0.05 in 1974).

**** Includes coal, coke, and other fuels such as propane.

EXHIBIT 2051-4

ENERGY CONSUMPTION PER UNIT OUTPUT IN THE PERISHABLE BAKED GOODS INDUSTRY (SIC 2051)

Product Group	Electricity Btu/Pound	Hot Water Btu/Pound	Steam Btu/Pound			Direct Fuel Btu/Pound	Exhaust Stream	
			To 300°F	300-500°F	Over 500°F		Temperature °F	Energy Btu/Poun
Bread and Rolls	244.1*	22.2	365.8	--	--	723.3	--	--
Cakes, Pies Doughnuts	234.5*	8.9	467.9	--	--	571.4	--	--

* Using 3413 Btu/kWh

EXHIBIT 2051-6

HISTORICAL AND PROJECTED U.S. PERISHABLE BAKED GOODS PRODUCTION, 1967-2000

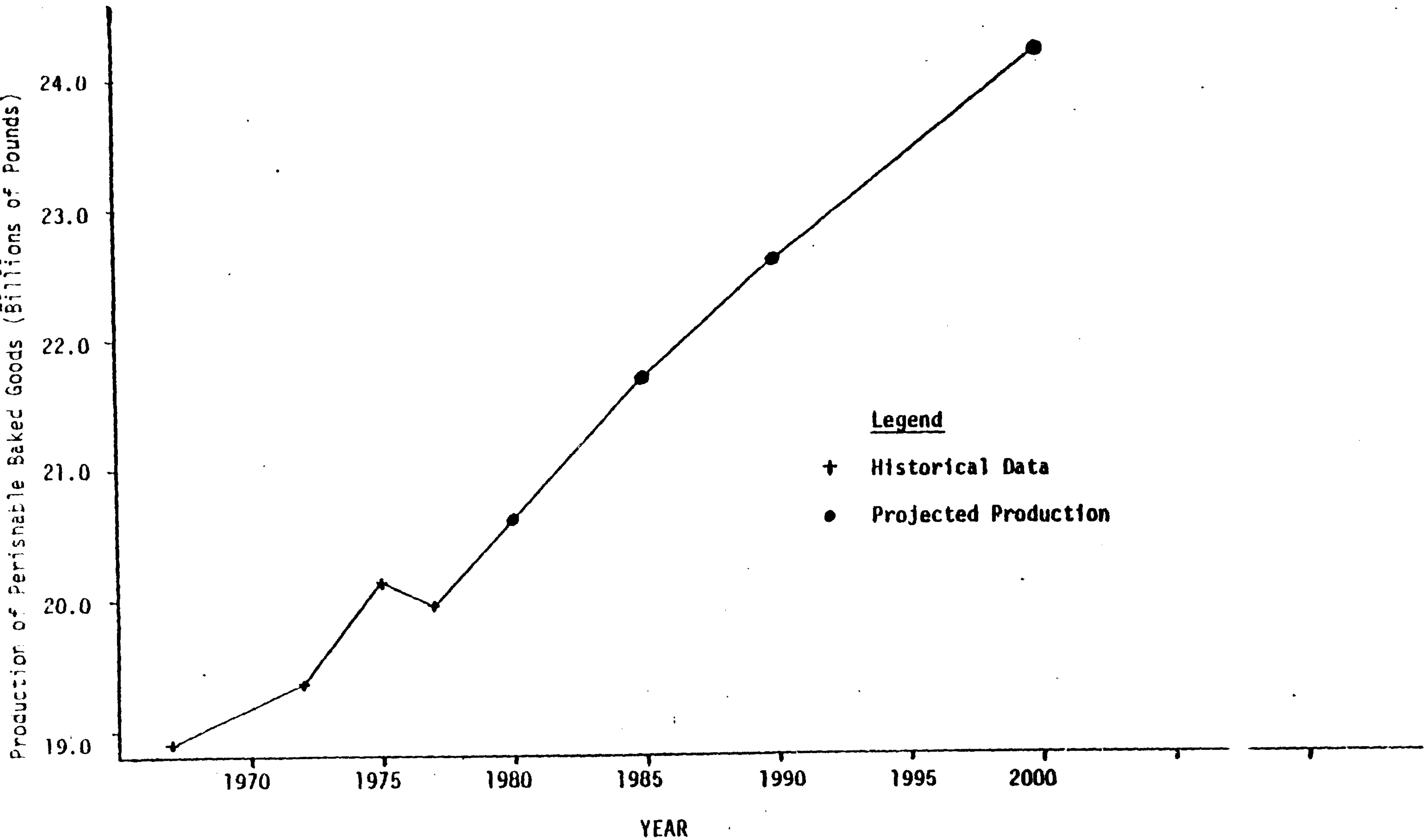


EXHIBIT 2051-6

DERIVATION OF "TARGET" FROM COMPONENTS

Component	% of Purchased Fuel		% Energy Use		Compound Savings
Purchased Fuel	54%	Direct Use	Ovens	75%	19%
			Fryers	5%	5%
			Space Heat	10%	8%
			Hot Water	10%	15%
	46%	Boiler	Boiler loss and Aux.	35%	15%
			Space Heat	20%	7%
			Proof & Fermentation	15%	
			Hot Water	17%	15%
			Ovens	8%	
			Misc.	5%	
				Overall Boiler	17%
		21% Savings in Purchased Fuel			
Purchased Electricity	100%		Lighting	30%	16%
			Mixing	16%	
			Packing	13%	3%
			Refrigeration	13%	20%
			Ventilation	9%	15%
			Oven	9%	3%
			Compressed Air	8%	20%
			Misc.	2%	20%
		11% Savings in Purchased Electricity			

Source: Derived from D.P.R.A., "Target" Document for SIC 20.

EXHIBIT 2051-7

ESTIMATED ANNUAL ENERGY CONSUMPTION IN PRODUCTION OF PERISHABLE BAKED GOODS FOR SELECTED YEARS
(10^{12} Btu)

	1975[1] (Base Year)	1985[3]	2000[4]
Purchased Fuel	33.80	29.9	30.0
Purchased Electricity[2]	7.50	7.5	7.9

1. From Exhibit 2051-3

2. Electricity converted to Btu's at 3413 Btu/kWh.

3. 1985 estimate based on production of 21.7 billion pounds, 21% savings over 1975 purchased fuel use, and 11% savings over 1975 electric energy use.

4. 2000 estimates based on production of 24.2 billion pounds, 10% savings over 1985 purchased fuel use, and 5% savings over 1985 electrical energy use.

EXHIBIT 2051-8

PERISHABLE BAKED GOODS PLANT FACTORS

Typical Plant Capacity Pounds/Year	Plant Size Range Pounds/Year	Electric Load Factor	Thermal Electrical Coincidence Factor	Projected Applicability To 2000
30,000,000	100,000-50,000,000	0.56	1.0	Good

EXHIBIT 2051-9

BREAD AND ROLLS BAKERY
HIGH & LOW ELECTRIC DEMAND TIME PERIODS

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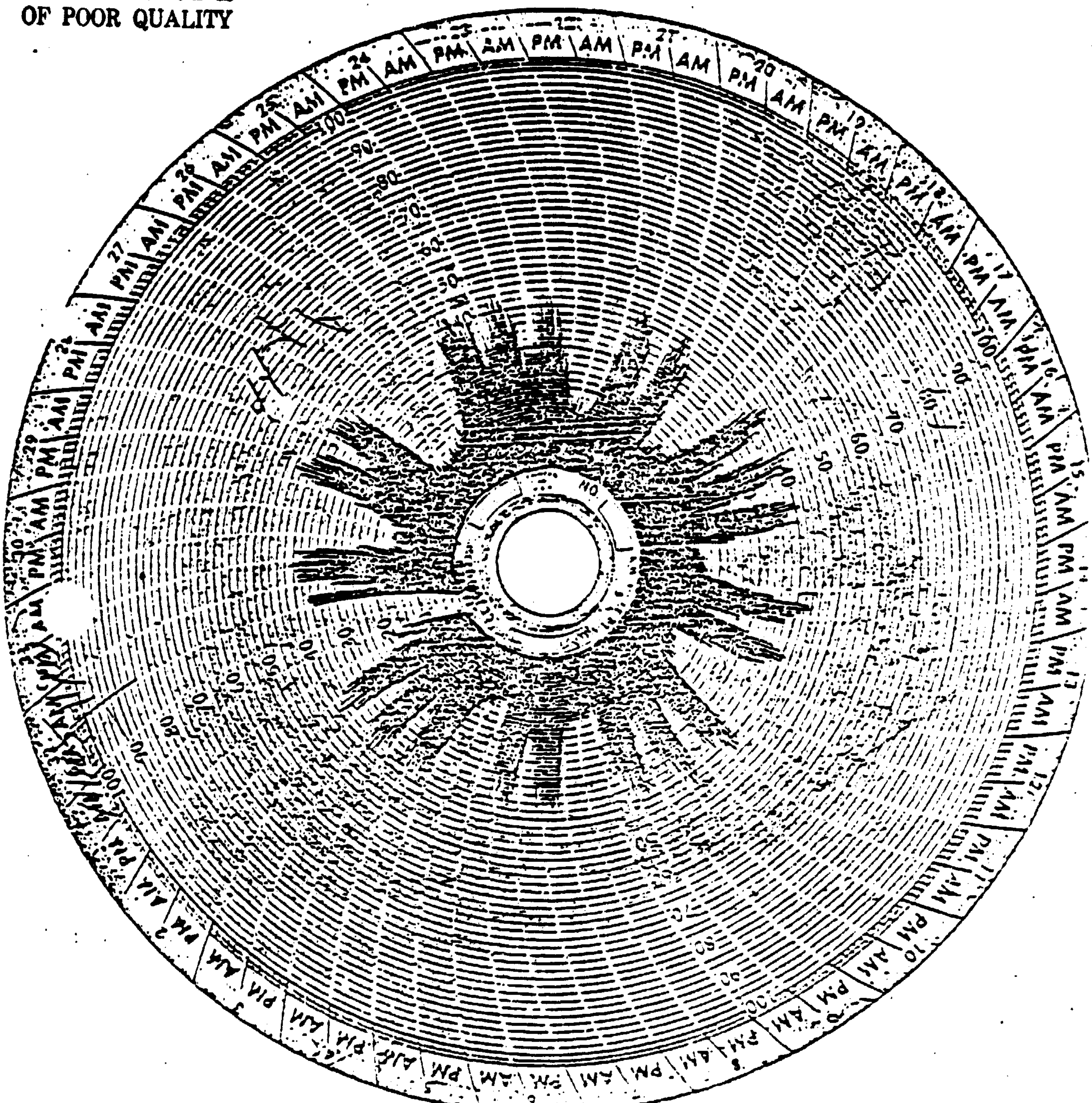
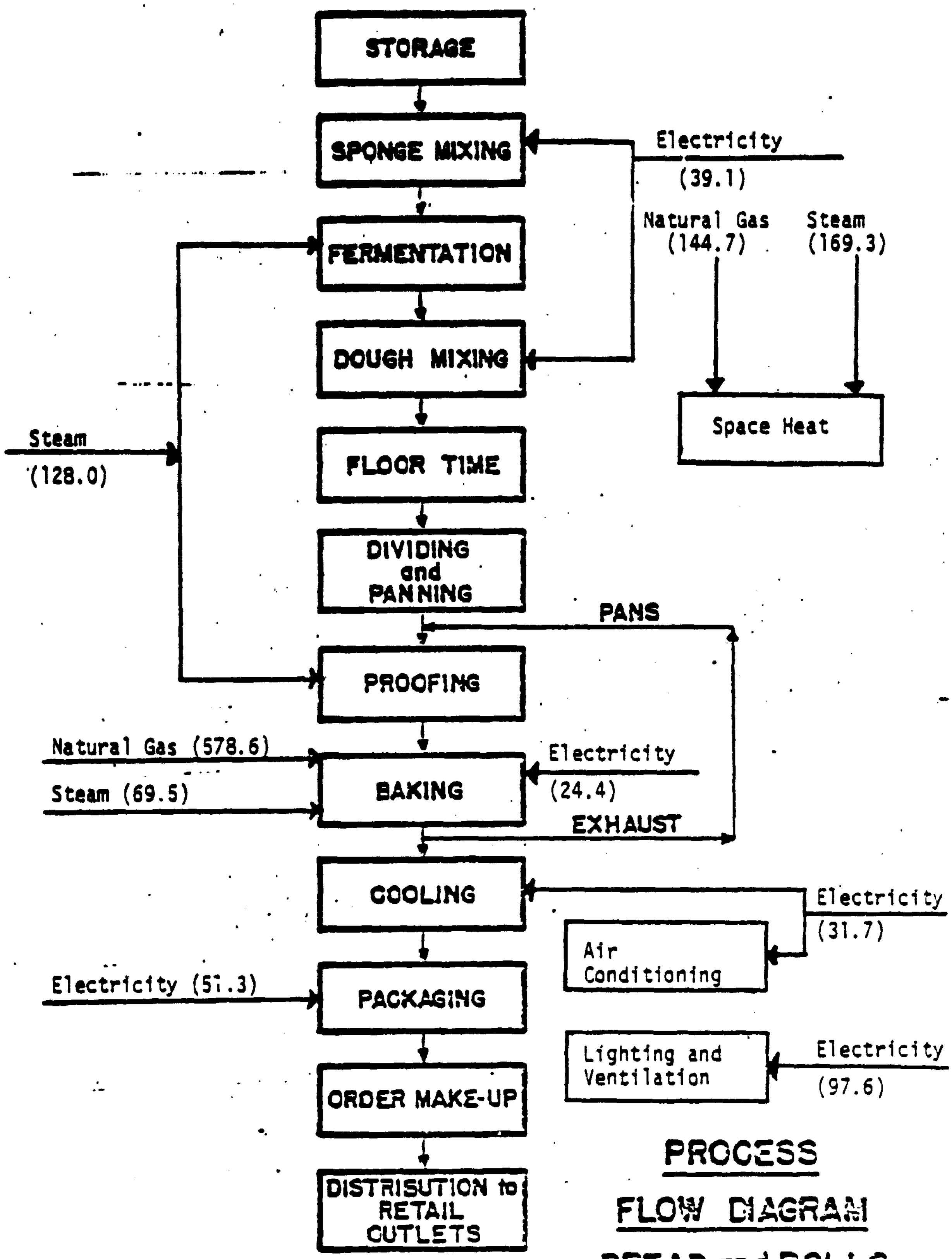
OF POOR QUALITY



Source: Johns-Manville Corporation, "A Study of Energy Conservation Potential in the Baking Industry", May 1976.

EXHIBIT 2051-10



PROCESS FLOW DIAGRAM BREAD and ROLLS BAKERY

All energy in Btu per lb of product
Electricity converted at 3415 Btu/kWh

Source: Derived from Johns-Manville Study and Gordian data.

MALT BEVERAGE PRODUCTION

1.0 PROCESS IDENTIFICATION

This section identifies and specifically defines the industry, and provides a brief description of the current production processes employed.

1.1 SIC Classification

The production of malt beverages is classified under SIC code 2082, which covers "establishments primarily engaged in manufacturing all kinds of malt beverages". Major products of SIC 2082 include beer, ale, malt liquor, porter, stout and brewers grain. Establishments primarily producing malt from grains are classified under SIC 2083.

1.2 Process Description

Lager beer is the most important product produced in the U.S. under SIC 2082, accounting for some 90% of the volume output of the malt beverage industry. Beer is defined as a carbonated alcoholic beverage produced by the fermentation of the water soluble extract of starchy raw materials. The major raw material (other than water) is malt which is produced from barley grain. Other grains sometimes used in conjunction with malt are rice, corn, wheat, oats and unmalted barley. The blossoms of the female hop plant are added to the beer to provide flavor and aroma.

There are many types of beers and other malt beverages. The major varieties are described below[1]:

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1 "Kirk-Othmer Encyclopedia of Chemical Technology", Second Edition, Volume III, John Wiley and Sons, New York 1964.

Lager Beers: These beers are stored after fermentation in cold closed tanks to improve their flavor and clarity. Lager beers are produced with yeast that settles to the bottom after fermentation (bottom fermenting yeast). The principle types of lager beers are named for the German cities where they were originally produced. These beers are:

Pilsner - a light beer with a medium hoppy taste containing 3.0-3.8% alcohol by weight. Most beer produced in the U.S. is of the Pilsner variety.

Dortmund - a pale beer with more body in taste, but less hops then Pilsner beer. Alcohol content ranges from 3.0-3.8% by weight.

Munich - a dark brown beer with a sweet, mildly hopped taste. Alcohol content ranges from 2.5-5.0% by weight. Bock beer is a form of Munich beer.

Ales: These are malt beverages with alcohol contents from 4.0-5.0% by weight with a pronounced hoppy taste. Ale is produced by yeast which floats to the top after fermentation (top fermenting yeast). Ales were originally produced in England.

Top Fermented Beer: These are produced with top fermenting yeasts. Some major beers of this type are:

Porter - a beer brewed with dark malt, which is sweeter and less hoppy than ale. Porter contains around 5% alcohol by weight.

Stout - a very dark, sweet beer containing 5-6.5% alcohol by weight.

Lambic - a beer made from 60% malt and 40% wheat, with a very hoppy taste. This beer is produced only in Brussels. Lambic beer is fermented and aged generally for 2-3 years.

Malt, which is produced by facilities classified under SIC 2083, is the most important raw material in the production of beer. Malt is produced from barley grain by allowing moist grain to germinate, and then drying the grain to produce malt. The method in which the gain is dried determines the taste and color of the malt.

Exhibit 2082-1 presents a schematic process flow diagram for the production of beer. It is important to note that no two breweries produce beer in exactly the same way, the variarions existing in the recipe and process employed.

The production of beer begins with the grinding of the malt. This is done to separate the extract yielding portion of the malt from the husks. The husks serve to aid filtration in downstream operation.

The ground malt is mixed with heated water in mash tubs, where the process of mashing takes place. A portion of the malt is charged into a cooker along with pre-ground grains which may include corn, rice, wheat or un-malted barley for mashing. Mashing has two principle purposes. Firstly, it dissolves the water soluble substances, and it permits the breakdown of substances in the grain by the action of enzymes, so that these substances (proteins and carbohydrates) are water soluble.

There are four major mashing methods. The first method, known as the three-mash method, starts with the entire charge at 35°C. A portion of the mash is removed, heated until boiling, and then returned to the main mash. The temperature of the main mash is then raised to 50-55°C. Next a second portion is withdrawn, heated until boiling and returned to the main mash. The main mash is then raised to 60-62°C. A third mash is withdrawn, heated to boiling and returned to the main mash. The temperature of the main mash is then raised to 75°C completing the

mashing process. A one-mash and two-mash process are also occassionally used[1].

The fourth mashing process, known as infusion, is used for mashing English type beers and ales. In this method the entire mash is gradually heated, often short of the boiling point, as boiling may destroy the enzymes.

The mash, composed of ground grains, a portion of the malt, and heated water is charged into a cooker. The temperature of the mixture is increased so that boiling takes place. This mixture is then added to the main mash.

After mashing is completed, the extract is separated from the spent grains via filtration. This filtration can be achieved by using a filter or lauter tub. A lauter tub is a cylindrical tank equipped with a slotted plate bottom. The spent grains collect on the plates and serve to filter the extract. The spent grains are sparged with hot water to recover the extract contained in the spent grain. The liquid extract is known as wort.

The spent grains may be sold wet, or dried, as livestock feed. These grains are known as brewers spent grains.

Brew kettles are charged with wort and hops (the blossom of the female hop plant) where the mixture is boiled. The brewing process serves three purposes. Firstly the boiling concentrates the wort via evaporation. Secondly the oils contained in the hops are extracted into the wort. It is these oils which enhance the taste and aroma of the beer. Finally the brewing process tends to cause the precipitation of

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1 "Kirk-Othmer Encyclopedia of Chemical Technology", Second Edition, Volume III, John Wiley and Sons, New York 1964.

insoluble matter (sludge). The wort is generally boiled for 1.5 to 2 hours at atmospheric pressure.

Following brewing the wort is passed into a hop separator where the spent hops (and some of the sludge) are strained out of the wort. The wort is next passed through coolers so that the wort is rapidly cooled. Sterile air is mixed with the wort in the coolers, as the yeast used in the fermentation step require oxygen[1].

The cold wort is now ready for fermentation. Brewers yeast is added to the wort in fermentation tanks. The wort entering the fermenation tank is generally between 6 to 10°C. Fermentation proceeds for about 10 days. Normally 1-2 pounds of yeast are added per barrel of wort (1Bbl=31 gallons).[2]

Excess yeast is removed in collecting tanks, after fermentation is complete. There is about five times as much yeast in the wort after fermentation as was added to the fermentation tanks. The collected yeast is used for subsequent fermentations, with the excess being dried and sold as brewers yeast. Brewers yeast has a protein content in excess of 60%, and is high in B vitamins. It is used as animal feed, human food supplement and in pharmaceutical products.

The fermentation product (often referred to as green beer) is cooled, strained and placed in closed vats called lagering tanks. The lagering process allows the green beer to age and fermentation to continue. The fermentation rate may be moderate at first, but quickly drops to a slow rate in the lagering tanks. It is believed that ... ier alcohols present in the green beer are converted into esters during lagering.

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1 United States Brewers Assn., "Description and Flow Sheet of Brewing Process", Appendix II, April 1, 1974.

2 "Kirk-Othmer Encyclopedia of Chemical Technology", Second Edition, Volume III, John Wiley and Sons, New York 1964.

These esters help give the finished beer its aroma and taste. Lagering time may range from two weeks to several months.

Following lagering, the beer is filtered in order to remove any sediment or other particles which might make the beer appear hazy. Generally the beer is filtered twice. Some U.S. brewers carry out the first filtration through Kieselguhr filters.

The beer, as it leaves the lagering tanks, contains dissolved carbon dioxide. The level of carbon dioxide is usually below the level desired in the finished product. Carbon dioxide gas, given off in the fermentation and lagering tanks (as by product of fermentation) is collected, compressed and stored as a liquid. The beer is then re-carbonated prior to, during, or just following the final filtration. The finished beer is then stored in pressurized tanks prior to packaging. The finished beer is kept under pressure (with carbon dioxide) to prevent carbon dioxide loss. The storage vessels must be sterile to prevent undesirable organisms from infecting the beer.

Finished beer is usually packaged in three forms; cans, bottles, and kegs. The simplest (and oldest) form of packaging is the keg. The kegs, constructed of aluminum stainless steel or wood, are cleaned and sterilized and are then mechanically filled. The process of filling kegs is known as racking, and the beer is known as draught beer. Kegs are usually intended for the local market, and therefore are not pasteurized. As a result kegs should be kept refrigerated to prevent spoilage.

Bottles used to package beer are first cleaned. This is often accomplished with a weak caustic solution at 70-80°C. The cleaned bottles are then sprayed with filtered water and filled with beer. The

beer may be pumped from storage, or may be conveyed by carbon dioxide pressure. The filled bottles are then crowned, after which point the beer is ready for pasteurization.

The purpose of pasteurization is to destroy the microorganisms which are likely to develop in the beer. This makes the beer biologically stable, increasing its shelf life and eliminating the need for refrigerating the packaged product. The process was first patented by Louis Pasteur in 1865 (and was originally developed with the wine and beer industry in mind). In a modern facility, packaged beer is heated for 20 minutes until reaching 60°C, kept at 60°C for 20 minutes, and cooled to 20°C during 20 minutes. A newer short time process heats the beer prior to packaging up to a temperature of 70°C, which is maintained for 30 seconds, after which the beer cooled. The total process takes about 2 minutes.[1]

Another way in which beer is frequently packaged is in cans, which also protects the beer from ultraviolet light which can cause the beer to break down. Tin plated steel cans were previously the most popular, however aluminum cans are gaining in popularity. The cans must be coated with a lacquer on the inside to prevent the reaction of the metal can with the beer. Canning is carried out in the same manner as bottling. Canned beer is pasteurized in the same way as bottled beer.

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1 "Kirk-Othmer Encyclopedia of Chemical Technology", Second Edition, Volume III, John Wiley and Sons, New York 1964.

2.0 NATIONAL DATA

The annual national data presented in this section are summarized in Exhibit 2082-2. The derivation and significance of the production and energy consumption data are discussed in the following sub-sections.

2.1 Capacity and Production Data

Total U.S. brewing capacity was 190 million barrels in 1977. Production for the same year was 156 million barrels (not counting losses) [1]. Barrels in the malt beverage industry refer to beer barrels of 31 gallons.

In 1976 there were 96 breweries operating in the U.S. [2] The brewing industry tends to be located near its market center. As a result breweries operated in 31 states in 1976.

Plant sizes can range from very small to very large. Adolph Coors Company operates what is believed to be the world's largest brewery. This facility has the capacity to produce 15 million barrels per year, and is located in Golden, Colorado. There are several small plants with production under 50 thousand barrels per year. The smallest brewery in the U.S. is the New Albion Brewery of Sonoma, California. Production is about 624 barrels per year. [3] A plant producing 2,000,000 barrels of beer per year would be typical of the larger size facilities. Exhibit 2082-3 shows the capacity and production for U.S. brewers, broken down by company for the year 1977.

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1 "Beverage Industry", February 10, 1978, Magazines for Industry, New York, page 1.

2 Bureau of the Census, "Statistical Abstract of the U.S.", October 1977, page 811.

3 "Newsweek", September 4, 1978, page 61.

2.2 Annual Energy Consumption

The U.S. Census Bureau reports the following consumption of energy in 1975 by SIC Code 2082[1].

1975 Energy Consumption, SIC 2082

Energy Source	Consumption
Distillate Fuel Oil	5.72×10^{12} BTU
Residual Fuel Oil	6.38×10^{12} BTU
Natural Gas	24.27×10^{12} BTU
Other*	3.90×10^{12} BTU
Purchased Electricity	1900×10^{6} kWh
Self Generated Electricity**	140.9×10^{6} kWh

* Includes coal and fuels such as propane

** Fuels used to generate electricity on-site are already included in the individual fuel consumptions above.

Malt beverages are the only major products classified under SIC Code 2082 (see Section 1.1). Therefore the energy consumed in producing malt beverages in the U.S. should correspond to the energy figure reported for SIC 2082 in the Annual Survey of Manufactures.

Natural gas and fuel oil supply the bulk of the fuel requirements for the industry. According to the Census Bureau the malt beverage industry generates less than 7% of its own requirements for electric power.

1 U.S. Department of Commerce, "Annual Survey of Manufactures", Fuel and Electric Energy Consumed, 1975 Edition.

3.0 PROCESS ENERGY REQUIREMENTS

The sub-sections which follow describe in depth the energy consumed per unit of production in malt beverages manufacture, as well as providing detail on the types of energy required. A summary of the energy requirements per unit output appears in Exhibit 2082-4.

3.1 Unit Energy Consumption Data

Although the production of malt beverages would not be considered to be very energy intensive, energy use in the industry is very important due to the vast quantities of product manufactured every year (158 million barrels in 1975).

The unit of production most often used in this industry is the barrel, equivalent to 31 gallons. Unit energy consumption data are presented in terms of 10^6 BTU/Barrel. Electrical energy is converted to BTU at 3413 BTU/kWh.

Most of the energy required for the production of malt beverages is supplied by steam. Electric energy, and in some plants direct fuel in the form of natural gas, supply the remaining energy requirements. Unit energy requirements are presented in Exhibit 2082-4, where ranges of values are reported to illustrate differences in energy consumption levels among plants. These variations in unit energy consumption levels are not necessarily a function of plant size, but may be a function of the particular process employed by the individual brewer. As mentioned in Section 1.2 of this report both recipe and process variations generally exist between brewers. In other words, no two breweries produce beer in the same way. Unit energy values reported in this report are representative of larger breweries.

3.2 Details of Electricity Consumption

Breweries generally operate continuously, 24 hours a day, 7 days per week. Some smaller breweries may operate 6 days per week part of the year and 7 days per week during peak sales periods (generally late spring and summer). Electric load factors in brewing plants usually are near 80%.

Most brewers purchase electric power from a public utility company. In 1975, facilities operating under SIC Code 2082 self generated 6.9% of their total electrical energy requirements. [1] One large brewer reports that 65% of the electrical requirements for his plant are met by self generated electric power. Smaller plants are less likely to self generate electric power.

For the industry as a whole electric power usage is divided among major end uses as follows [2]:

Mechanical Power	41%
Refrigeration and Compressed air	27%
Lighting	29%
Drying and Other Misc.	3%
	100%

3.3 Details of Thermal Energy Consumption

Steam is the primary source of thermal energy in brewing plants; some 0.20 to 0.27 million BTU/Barrel of energy is supplied by steam, generally at temperatures below 300°F (except where breweries self-generate electric power, in which case steam may be generated at

1 Derived from: U.S. Department of Commerce, "Annual Survey of Manufactures", Fuels and Electric Energy Consumed, 1975 edition.

2 Development Planning and Research Assoc., Inc., "Energy Efficiency Improvement Targets - Food and Kindred Products Industry", June 30, 1975, p.7-8.

temperatures above 500°F and let down to process temperatures through a turbine).

Brewing plants use water as a principle raw material. Water is heated using steam, however the purity of the water used is crucial to the quality of the finished product and it is therefore unlikely that brewers would use hot water derived as a waste stream from cogeneration.

Some brewing plants use some direct fuel for spent grain drying. Direct fuel requirements (in the form of natural gas) are estimated to range between 0.00 and 0.02 million BTU/Barrel.

Steam is divided among its major end uses as follows [1]:

	%
Cookers	4.4
Mash Mixer	3.3
Brew Kettle	30.6
Spent Grain Drying	17.0
Effluent Concentration	4.7
Soakers	11.3
Pasteurizers	28.7
	100.0

1 Derived from: Masters Brewers Association, "The Practical Brewer", 1977, Madison, Wisconsin, p.341.

4.0 ANTICIPATED TRENDS

This section discusses the trends which are likely to occur in the industry through the year 2000. The major emphasis is on two areas: marketing and energy consumption.

4.1 Product Growth Trends

In 1976, 150.4 million barrels of malt beverages were produced as packaged and draught beverages (total withdrawals)[1]. Of this total 12.1% was produced as draught beverage.

Malt beverage production tends to be greater in the summer months. The table below illustrates the seasonal variations in production experienced by the U.S. malt beverage industry in 1976 [2]:

Month	% Total Annual Production
January	7.2
February	7.3
March	7.3
April	8.6
May	9.0
June	9.4
July	10.0
August	9.9
September	8.9
October	8.1
November	7.0
December	7.2
	100.0

Although the number of breweries has been declining for some time in the U.S., the production of beer and other malt beverages has been increasing steadily. It is expected that the output of the industry will continue to expand through the year 2000. There are two methods used in this study for predicting future production of malt beverages.

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1 Production on which tax is paid.

2 United States Brewers Association, "Statistical Memorandum Number 590", April 1976.

The first method is based on trends in per capita consumption and population. The alternative method uses a linear projection based on historical production data.

Per capita consumption of domestically produced beer has been increasing in recent years. The table below presents data on per capita beer consumption from 1960 to 1976 (based on Bureau of Census population estimates for adults 18 years of age and older) [1]:

Year	Per Capita Domestic Beer Consumption (gallons)
1960	23.91
1965	25.29
1970	28.35
1972	29.23
1973	29.45
1974	30.75
1975	32.43
1976	31.09

The per capita consumption of beer is expected to continue to rise. Future levels of beer consumption can be predicted if a power curve behavior is assumed ($y = a\ x^b$). The future per capita consumption of malt beverages is predicted as follows by a least squares fit of the above relationship:

Year	Per Capita Domestic Beer Consumption (gallons)
1980	31.12
1985	31.78
1990	32.33
2000	33.23

The increase in leisure time available and the advent of "light" beers are factors tending to support the trend toward increased per capita consumption. Historical and projected per capita consumption

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1 U.S. Bureau of the Census, "Statistical Abstract of the U.S.", October 1977, p.811.

of malt beverages are shown in graphical form in Exhibit 2082-5.

The above projections can now be utilized in making future production estimates. Per capita consumption figures are multiplied by population (over age 18) estimates to yield expected levels of future consumption.

Year	Population (over age 18)[1] (millions)	Projected Beer Production (millions of barrels)
1980	160.174	160.8
1985	170.587	174.9
1990	178.737	186.4
2000	191.401	205.2

A second estimate of future production of malt beverages can be made by using a least square linear projection based on historical production data. The following projection result from the above analysis:

Year	Projected Beer Production (millions of barrels)
1980	163.7
1985	182.2
1990	200.6
2000	237.5

Both sets of projections, as well as historical production data, are presented in graphical form in Exhibit 2082-6.

4.2 Process Changes and Implementation of New Technology

The basic brewing process existed 5000 years ago. Many brewing plants which exist today are over 50 years old. New plants tend to be more efficient because of their larger size, and the use of computer control has allowed breweries to operate in a continuous or nearly continuous manner. This has allowed an increase in productivity and a decrease in labor requirements.

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1 U.S. Bureau of the Census, "Statistical Abstract of the U.S.", October 1974, p.6 Series II Projections.

In a recent study conducted under the CCMS Rational Use of Energy Programs, brewers from Belgium, Holland, Germany, the U.K. and the U.S. listed ideas for possible research, development and demonstration activities designed to reduce energy consumption. The following is a listing of those ideas[1]:

MALTING

- Use double-floor kilns.
- Use heat pumps (specific application was not given).
- Consider steeping, germination, and kilning in same box.
- Reduce germination time.
- Investigate use of malt containing a higher moisture content.
- Use air-cooled condensers to provide heat for kilns.

BREWING

- Consider recycling hot water by heat exchangers.
- Optimize the frequency of cleaning/disinfecting methods.
- Minimize evaporation rates.
- Minimize boiling times.
- Consider heating in a closed circuit under pressure with an exchanger.
- Consider wort heating outside the copper.
- Consider heat pumps to recover low-grade heat for preheating brewing liquor.
- Consider use of whirlpools or settling tanks instead of separators.
- Consider use of copper vapors to provide refrigeratic ith an absorption unit.

FERMENTING

- Develop a yeast strain to ferment at the temperature of the surrounding atmosphere.

1 Resource Planning Association Inc., "Briefing Materials for the Third Brewing Industry Exports Meeting", Washington, D.C. April 3-4, 1978.

- Use maximum-sized tanks.
- Minimize the fermentation time.
- Use closed-circuit automatic cleaning.
- Further mechanize and automate the cleaning procedure.
- Investigate a method for cooling only the tanks, and not the working floor.
- Limit reevaporation in tanks that are externally cooled with ammonia.

STORAGE AND FILTRATION

- Individually cool insulated tanks,
- Filter in the cold block (cellars).

PACKAGING

- Use short, simplified, standardized bottling lines and packaging methods.
- Recycle the following items to the maximum extent possible: beer rests, glass, cartons, crown corks, and scrap.
- Consider aseptic bottling.
- Fill at higher temperatures, rack at higher temperatures (e.g., 10° or 15°C).
- Use one-way glass instead of returnable bottles.
- Minimize packaging materials.
- Use standard keg types.
- Use cold sterilization techniques.

ELECTRICITY AND LIGHTING

- Control the efficiency of machines and motors.
- Consider generating own electricity and/or steam by back-pressure generation.
- Consider using gas turbines for provision of heat and electricity and direct drive for compressors.
- Convert V-belt drives to flat-belt drives.

WATER

- o Recycle the water utilized by various packaging machines.
- o Recycle waste water.

STEAM AND GENERAL

- o Control the ventilation and heating of the halls automatically with timers and thermostats.
- o Use pipelines (air, carbon dioxide, vapor) that can be closed in the evening when work is finished, to avoid losses during the night and weekends.
- o Either keep doors open or closed when appropriate to minimize space heating or cooling needs; install strip doors to minimize heating, ventilation, and air conditioning needs.
- o Regularly clean heat exchangers and condensers to obtain maximum efficiencies.
- o Use waste heat from steam-boiler stack to preheat boiler feed water.
- o Recover the heat from boiler blowdown.
- o Consider heat storage to even out loading on boilers.
- o Use solar power to preheat boiler feedwater.
- o Decentralize boiler services to reduce distribution losses.

The extent to which the above ideas may be implemented will depend upon their development and will be for the most part an economic decision.

4.3 Trends in Energy Requirements

In setting the energy efficiency improvement "target" for SIC 20, sub component data for SIC 2082 was presented. The component "target" for SIC 2082 is a 5% net reduction in unit nergy consumption by 1980 relative to 1972 energy consumption levels.

C-2

If the assumption is made that a 5% reduction in unit energy consumption can be achieved in 1985 relative to present energy consumption levels, and an additional 5% reduction in unit energy levels can be achieved by the year 2000, then the energy consumption figures for these years can be estimated. It is not expected that more than a 5% reduction in unit energy consumption will be achieved by the year 2000 relative to 1985, as energy use is only one of many important considerations in the industry (e.g. purity of product, taste considerations etc.). The average of the straight line and population based product growth projections of Section 4.1 were used in preparing the future energy predictions, which are presented in Exhibit 2082-7.

The purchased fuels in 1975 were broken down as follows:

	%
Natural Gas	60.3
Oil	30.0
Other (including coal)	9.7
	100.0

It is not expected that the energy consumption pattern will vary by 1985. If it is assumed that 50% of the new capacity added after 1985 is to be fueled with coal, then the following energy use pattern can be predicted for 2000:

	%
Natural Gas	56
Oil	28
Other (including coal)	16
	100

5.0 PLANT-SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements, including indications of load profiles, state conditions, and reliability considerations. Several plant factors are summarized in Exhibit 2082-8.

5.1 Load Profiles

Electric power load factors in the malt beverage industry are generally around 0.80. As mentioned previously large brewers generally operate 24 hours per day, seven days per week. Smaller brewers may operate 5-6 days per week during periods of slack demand. Refrigeration equipment will operate whenever beer is being produced, although packaging lines may not always operate continuosly particularly in smaller facilities. It is estimated that the thermal-electrical coincidence factor in breweries is approximately 1.0.

5.2 Energy Flow Schematics

A schematic diagram illustrating how various types of energy are utilized in an industry average brewing plant is presented in Exhibit 2082-9. For data on specific unit energy requirements, refer to Exhibit 2082-4.

5.3 Mass Flows

The following materials were consumed at U.S Breweries in 1977. These major raw materials are expressed as pounds consumed per barrel produced [1].

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1 U.S. Brewers Association, "Statistical Memorandum Number 590", April 17, 1978.

Item	Quantity (lb/Bbl)
Malt and Malt Products	25.1
Corn and Corn Products	10.4
Rice and Rice Products	4.1
Barley and Barley Products	0.17
Soybean and Soybean Products	0.006
Sugar and Syrups	1.5
Hops	0.17
Hop Extracts	0.03

5.4 Reliability Considerations

It is important for a malt beverage production facility to have a reliable source of electric power. Large plants which generate their own power remain connected to an electric utility to ensure their source of power.

Should a power failure occur, several problems will arise. Firstly the filtration system will go down. This means the filters will have to be re-coated before they can be re-started. Some loss of product will occur in the brewhouse. Grain will settle to the bottom and can cause the agitators to become grain locked. The system will have to be emptied and cleaned before production can begin again. A power failure of long duration could result in the loss of product undergoing fermentation and lagering if the temperature becomes too high.

EXHIBIT 2082-1: PRODUCTION OF BEER

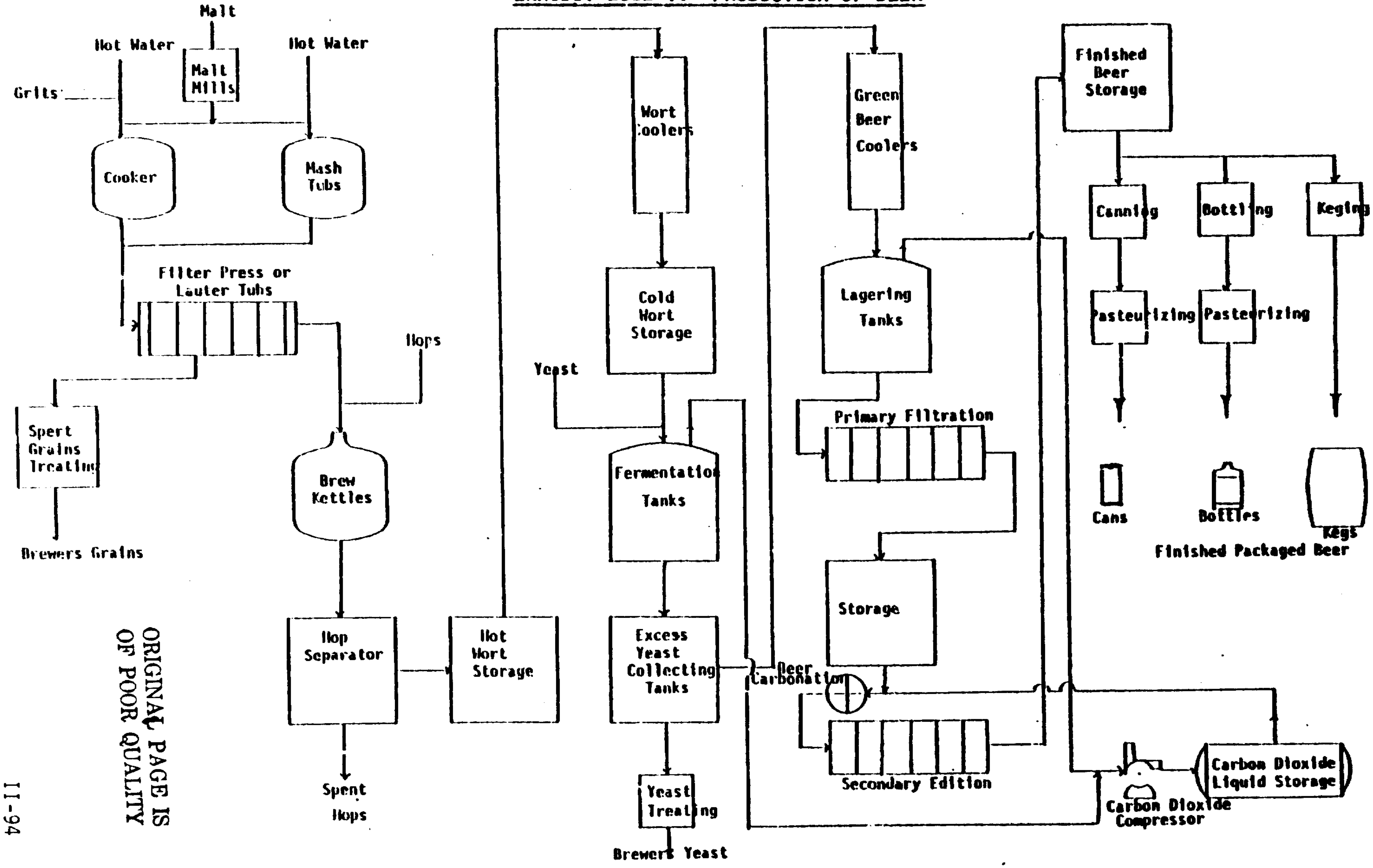

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EXHIBIT 2082-2

ANNUAL NATIONAL DATA (1975), THE MALT BEVERAGE INDUSTRY

Product Production - Million Bbl	Total Energy Consumption Trillion Btu	Purchased Electricity - Trillion Btu	Purchased Fuels Trillion Btu	Coal	Oil	Gas	Other	Total Energy Consumption For SIC Trillion Btu	Percent Total Energy Consumption Represented
158.0	46.75*	6.48*	40.27	**	12.10	24.27	3.90	46.75	100

* Purchased electricity converted to Btu at 3413 Btu/Kwh

** Included with other fuels as the Census Bureau does not report coal use separately in order to avoid disclosure of data from individual companies.

EXHIBIT 2082-3

U.S. MALT BEVERAGE PRODUCTION AND CAPACITY - 1977
(Millions of Barrels)

COMPANY	PRODUCTION	CAPACITIES
Anheuser-Busch	37.1	43.0
Miller	24.3	26.0
Schlitz	22.0	29.0
Pabst	16.0	18.5
Coors	12.7	15.0
Olympia	6.9	9.2
Heilerman	6.3	8.0
Stroh	6.1	7.0
Schaefer	4.8	6.5
Carling National	4.4	5.6
General	4.0	7.0
Schmidt	3.6	4.3
Genesee	2.8	3.0
Pearl	1.1	1.8
Pittsburgh	0.7	1.3
All others	3.2	4.8
TOTAL	156.0	190.0

Source: "Beverage Industry", Feb. 10, 1978, p.1

EXHIBIT 2082-4

ENERGY CONSUMPTION PER UNIT OUTPUT* IN MALT BEVERAGE PRODUCTION

Electricity* Million Btu Per Unit	Hot Water Million Btu Per Unit	Steam (Million Btu/Unit)			Direct Fuel**** Million Btu Per Unit	Exhaust Stream	
		To 300° F	300-500° F	Over 500° F		Temperature °F	Energy Million Btu Per Unit
0.025-0.040	***	0.20-0.27	-	-	0.0 - 0.02	-	-

* unit output denotes one barrel of 31 gallons

** assuming 3413 Btu/Kwh

*** Hot water is produced from steam. Since the purity of the water is crucial to the product quality, it is unlikely that brewers will use hot water derived as a waste stream from cogeneration.

**** The primary use of direct fuel is for spent grain drying. Some facilities use no direct fuel for drying.

EXHIBIT 2082-5

HISTORICAL AND PROJECTED PER CAPITA CONSUMPTION OF MALT BEVERAGES

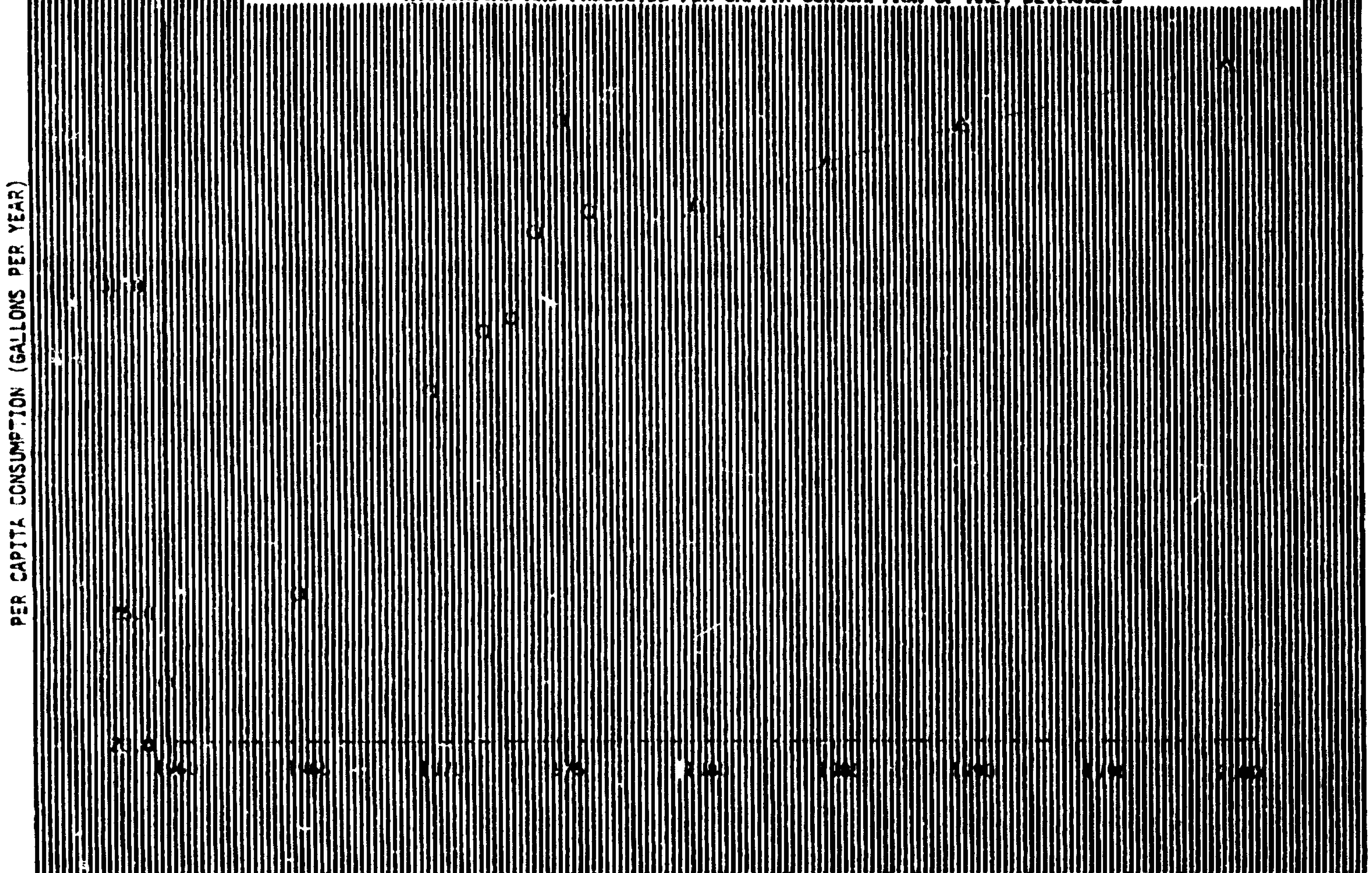

EXHIBIT 2082-6

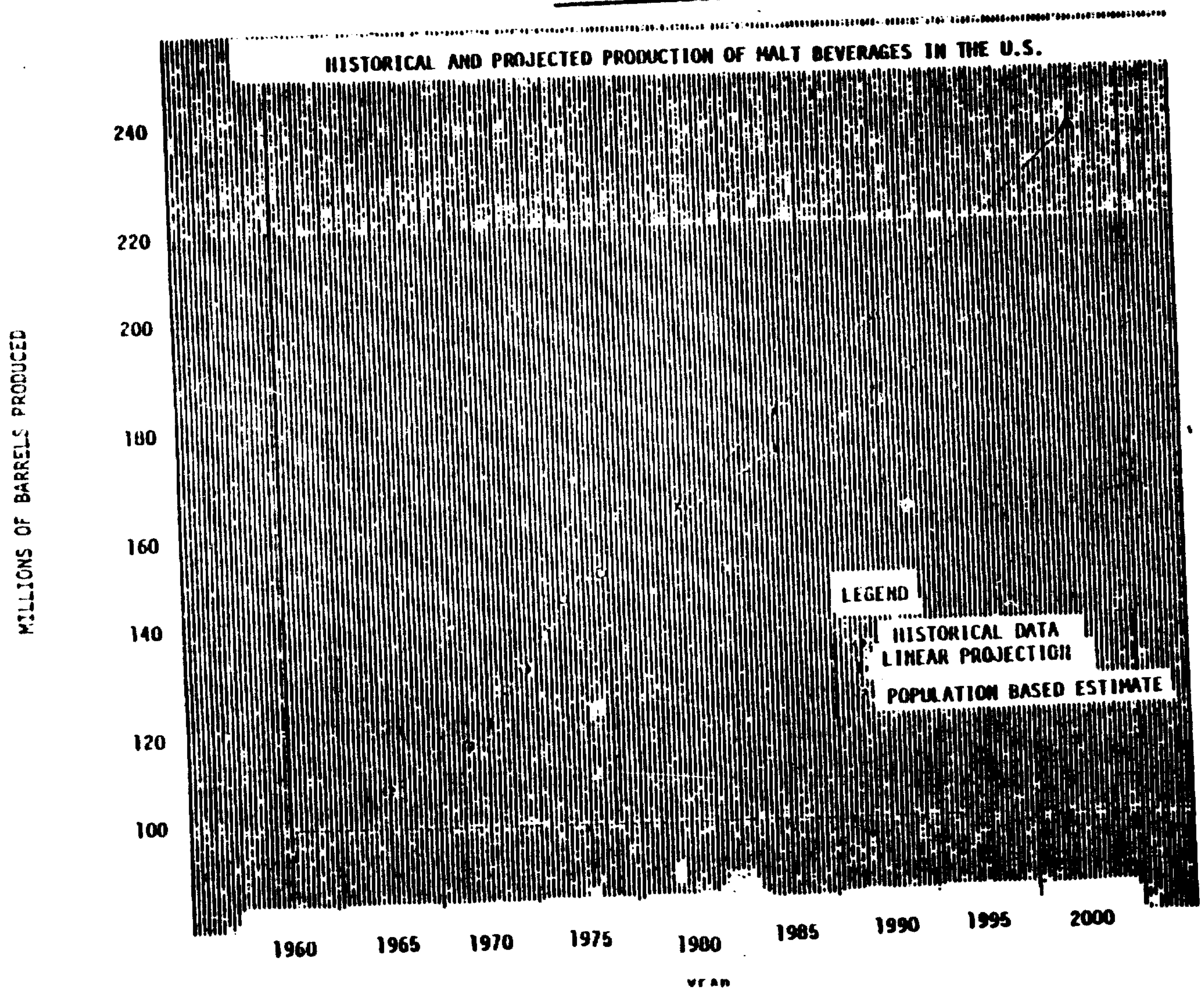

EXHIBIT 2082-7

ESTIMATED ANNUAL ENERGY CONSUMPTION IN MALT BEVERAGE PRODUCTION FOR SELECTED YEARS

(10^{12} Btu)

	1975 (1) (Base Year)	1985 (3)	2000 (4)
Purchased Fuel	40.27	43.2	57.5
Purchased Electricity (2)	6.48	7.0	9.3

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(1) From Exhibit 2082-2

(2) Electricity converted at 3413 Btu / KWH

(3) Data for 1985 based on the following assumptions:

a) Unit energy consumption 5% lower than 1975
b) Production of 178.6 million barrels in 1985 (average of the projections of Section 4.1)

(4) Data for 2000 based on the following assumptions:

a) Unit energy consumption 5% lower than 1985
b) Production of 221.4 million barrels in 2000 (average of the projections of Section 4.1)

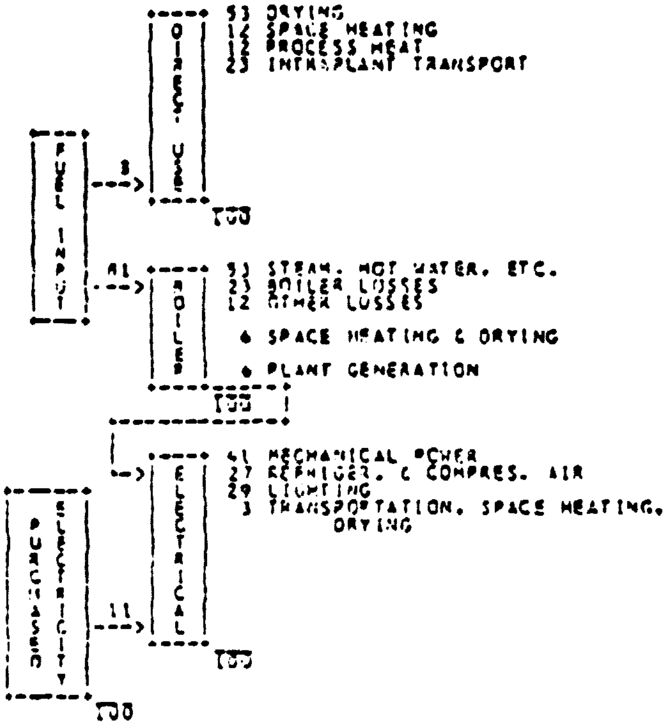
EXHIBIT 2082-8

MALT BEVERAGE PLANT FACTORS

TYPICAL PLANT CAPACITY (Barrels/Year)	PLANT SIZE RANGE (Barrels/Year)	ELECTRIC LOAD FACTOR	THERMAL ELECTRICAL COINCIDENCE FACTOR	PROJECTED APPLICABILITY TO 2000
2,000,000	624-15,000,000	0.8	1.0	Good

EXHIBIT 2082-9

ENERGY USE SCHEMATIC



Source: Development Planning and Research Associates Inc., "Energy Efficiency Improvement Targets - Food and Kindred Products Industry." June 30, 1976, p.7-8

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BROAD WOVEN FABRIC MILLS, MAN-MADE FIBER AND SILK

1.0 PROCESS IDENTIFICATION

This section identifies the standard industrial classification for the manufacture of broad woven fabrics of primarily man-made fibers and provides a description of the manufacturing process.

1.1 SIC Classification

The production of woven fabrics greater than 12 inches in width, of primarily man-made fibers and/or silk is classified under SIC code 2221, "Broad Woven Fabric Mills, Man-Made Fiber and Silk." Those establishments primarily engaged in weaving carpets and rugs and tire cord fabrics are classified under SIC codes 2271 and 2296, respectively. Mills primarily engaged in finishing (i.e., dyeing, bleaching, etc.,) broad woven fabrics of man-made fibers and/or silk are classified in SIC code 2262.

1.2 Process Description

Weaving is a simple process involving the interlacing of two or more sets of yarns at right angles, however, modern technology has added many complex variations to provide a diversity of process operations and end products.

Weaving mills, as classified in SIC 2221, exist in two forms: "greige" mills (pronounced "gray") which produce undyed, unfinished goods, or "integrated" weaving mills, which include finishing operations (i.e., bleaching, dyeing, texturizing, etc.) in order to produce finished goods. Today, integrated mills produce most of the woven fabric.[1] The type of end

product (i.e., sheets, upholstery, etc.) may further characterize a weaving mill but often many types of products are woven at one mill.

In turn, different types of looms are used to weave different products for which they are suited. There are five basic types of looms used today which vary fundamentally in the way filling yarns (the transverse or crosswise yarns) are carried through the warp yarns (the longitudinal or lengthwise yarns); they are the fly shuttle, rapier, missle, water jet, and air jet type looms.* Another type of loom is the "Jacquard" loom in which the warp yarns may be controlled individually by series of programmed punch cards to produce intricate patterns such as designs on upholstery, bedspreads, curtains, and towels, etc. The fly shuttle loom is the most commonly used, representing 90-95% of all the looms in operation today.(1)

The fly shuttle loom is supplied with warp yarns from a "loom beam"** while the filling yarn is supplied from a "quill". The loom beam is a beam (or tube) with the warp yarns wound around it. The loom beam contains

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* Fly Shuttle loom - the filling yarns are carried through the "shed" (space between the alternately raised and lowered warp yarns) by a a "shuttle" (projectile) carrying a quill. The shuttle is fired across through the shed by a "picker stick" (hammer). (See Exhibit 2221-1.)

Rapier loom - the filling yarns are carried through the shed by a gripper on a steel band driven by wheels on each side of the loom.

Missle loom - the filling yarns are inserted by tiny shuttles or projectiles, called darts, which carry their own supply of yarn and are fired across the warp yarns from a magazine by a torque spring.

Water jet - the filling yarn is carried by a tiny jet of water.

Air jet - the filling yarn is carried by a tiny jet of air.

** For some special types of looms, the warp yarns are supplied from a "creel." The creel is a structure containing several hundred positions, each furnished with a yarn package (cone or tube), from which the yarn is fed. Generally, creels are used when the yardage is short and the yarn is heavy, thus requiring fewer ends.

the exact number of warp yarn ends needed for the desired fabric, as many as several thousand ends and many thousands of yards long. Only one loom beam is usually mounted on a loom at any given time although some fabrics require the simultaneous use of two, three, or four beams. The quill is a small package (or tube) with the filling yarn wound around it. The yardage on a quill is relatively short and several quills are furnished for use on one loom.

A typical greige mill performs a variety of sequenced operations to prepare the raw material (staple or yarn) for weaving. An integrated mill includes these process steps plus additional finishing steps. A simplified process flow diagram is shown in Exhibit 2221-2.

The raw material may be in the form of bales of staple fiber or cartons of packages (tubes of wound yarn). The bales of stable fiber are unwrapped and loaded onto an opening machine. The fibers on the bottom of the bales are plucked at by steel fingers and then pneumatically conveyed to a blender where they are blended, also pneumatically. The fibers are moved to a picker which opens or loosens the staple fibers (separates them from each other) and then calenders them into a continuous, metered lap.* Then, the picker lap is moved to a card machine. The card plucks small tufts from the picker lap and transfers them to between a rotating cylinder and a rotating slat (like a bulldozer tread) both covered by fine sharp wire points. On this machine, the fibers are separated, aligned somewhat parallel, cleaned some more, and formed into a web.** The web passes

* Lap - staple fiber which has been made into a continuous sheet of uniform thickness and weight, made on a picker.

** Web - a continuous fibrous sheet, much thinner and finer than a lap, made on a card.

through rollers where it is formed into a sliver* (a rope-like strand) and then automatically coiled into a tall can. Next, multiple strands (or ends) of sliver go into the drawing frame; they may be blended at this point (i.e., polyester with cotton and/or rayon, etc.). The drawing frame combines the multiple strands of sliver (usually 6 or 8 strands) into one uniform sliver, drawn so that the newly formed sliver is of the same weight per length as one of the individual input ends. The newly formed sliver is transfered to a roving frame where it is drafted (or reduced) 10-25 times smaller in cross-section and unit weight and also twisted slightly in order to give it sufficient strength to withstand winding onto a spindle (bobbin). The input is usually one end of sliver for each end of roving**, with about 96 ends per machine.(1) In some processes, the roving step is by-passed and the sliver is sent directly to the spinning frame.(1) Spinning drafts the roving 15-50 times smaller or if sliver is spun directly, as much as 400 times smaller. In addition, the yarn is tightly twisted and may consist of one or two ends of roving or sliver spun into one strand of yarn. Following spinning, the yarn spindles are transfered to a winder which upgrades the yarn by using slub catchers to remove imperfections and rewinds it. From winding, some of the spindles are repackaged on a quills for filling yarn and some rewound onto beams for warp yarn, the latter is called "warping." Two systems of warping are commonly used, one system beams (or winds) the desired number of warp ends and yardage directly, while the other beams "section beams", each beam containing a fraction of

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* Sliver - pronounced sliver) a rope-like strand, made by condensing the web.

** Roving - sliver which has been drawn and reduced many times in unit weight with a little twist added.

the warp ends and an excess of the yardage for the loom beam (or fabric) ultimately desired; the two systems are typically used in small mills (50 to 300 looms) and large mills (500-1200 looms), respectively. Prior to weaving, the warp yarns undergo "slashing". In this process step they are coated with a chemical (called a "size" or "sizing material") to lubricate the yarns against the friction they will encounter on a loom. In addition, the section beams are assembled or repackaged onto one loom beam with the proper number of warp ends and yardage. In slashing, several section beams, totaling the desired number of warp ends, are mounted on a creel and all the ends are combined through a reed (guide) into a single sheet. This sheet is then passed through a "size box" where it is coated.* From the size box, the sheet of yarns pass over a set of steam heated cylinders or cans for drying (sometimes pre-drying is done by overhead lamps before going to the cylinders). Finally, the yarns are separated from the sheet, spaced, and wound onto a final loom beam, now they are ready to be entered into the loom elements. Weaving, as previously described in this section, may be performed on different types of looms and with a variety of weave patterns (plain, twill, or satin weave, etc.) to produce unfinished (greige) woven goods. The greige fabric is inspected and packed for shipping or, if produced at an integrated mill, sent to the dyeing and finishing operations.

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* Sizing Materials -

For spun yarns: Potato starch, gum, and synthetic compounds (such as polyvinyl alcohol).

For filament yarns: gelatine, polyacrylic acid, and other trade-named synthetic compounds.

Dyeing involves the following process operations: scouring, bleaching, dyeing or printing, and drying, heat-setting, or curing. Scouring washes the fabric in soap or solvent to remove sizes, soil, and to relax prior process tensions or built-in shrinkages. Bleaching whitens the fibers, improves the base for colors, and removes stains. Dyeing colors the fibers and drying, heat-setting, and curing dry the fabric, increase dimensional stability, pilling and wrinkle resistance, and prevent edge curling. In addition, some special treatment may be incorporated with these operations to provide special effects such as stiffening, water repellency, antistatic, flame proofing, etc. These operations are combined in a variety of sequences depending on the type of fiber, processing oils or lubricants, desired aesthetics of the finished product, finished product market value, and equipment available. Although a great variety of equipment is available for each operation, they are similar in that they are electrically driven and use steam for drying*, hot water, and/or direct agitation. They differ in the way fabric is handled (or processed), the form or type of product handled (i.e., piece goods, beams, packages, type of fabric, etc.) and the processing rate.

Finishing is performed to give a fabric its final aesthetic and functional qualities prior to fabrication for consumption (i.e., cutting, sewing). Some qualities may be attained chemically by applying finishes such as flame retardants, softeners, durable press resins, etc., while other qualities may be attained by mechanical means (i.e., "napping"-

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* Some drying, depending on the equipment, is performed by direct use of natural gas. Heat setting is normally performed by infrared radiation from a gas fired burner.

plucking fabric fibers to produce a hairy surface, "singeing"-burning off superfluous fibers, "decating"-removing wrinkles, etc.) in order to improve dimensional stability, shrinkage characteristics, surface characteristics, etc.

2.0 NATIONAL DATA

The annual national data for the manufacture of broad woven fabrics of primarily man-made fibers are presented in this section. A summary of production and energy consumption is shown in Exhibit 2221-3.

2.1 PRODUCTION DATA

Summarized below is the production of all broad woven fabrics composed primarily of man-made fiber for 1974 through 1977.

(2)
PRODUCTION
BROAD WOVEN GOODS, MAN-MADE FIBERS
(Millions of Linear Yards)

	1974	1975	1976	1977
100% Filament Yarn	1,963	1,695	1,951	2,024
100% Spun Yarn and Blends	3,309	3,037	3,522	3,569
All Other	659	554	614	626
Total, Broad Woven Fabrics of Man-Made Fiber	5,931	5,286	6,087	6,219
Weight of All Broad Woven* Fabrics of Man-Made Fiber (millions of pounds)	2,505	2,257	2,628	2,716

Some of the major companies contributing to the above production are:

Burlington Industries, Inc.
Collins & Aikman Corp.
Fieldcrest Mills
J.P. Stevens & Co., Inc.

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* Fabric weight was derived by using a conversion factor of 2.42 yds./lb. and 2.29 yds./lb. as determined by the U.S. Census Bureau for the first quarter of 1972 and 1977, respectively,(3) and then extrapolating to determine the conversion factors for the years in between.

M. Lowenstein and Sons, Inc.
Milliken & Co.
Monsanto Co.
Texfi Industries, Inc.
Westpoint Pepperell, Inc.

Broad weaving mills typically operate 24 hours per day, 6 days per week, depending on market demand. Mill production ranges between 25 MM lbs./year to 8.0 MM lbs./year for typical large and small mills, respectively. Normal production rates for typical or medium size mills average about 12 MM lbs./year.[1]

2.2 ANNUAL ENERGY CONSUMPTION

The U.S. Census Bureau reports the following energy consumption by fuel type for SIC 2221 in 1975[4]:

1975 ANNUAL ENERGY CONSUMPTION, SIC 2221[4]

Energy Source	Consumption (x 10^{12} Btu)
Fuel Oil	8.50
Coal	6.23
Natural Gas	11.26
Other*	2.00
Purchased Fuel (Total)	27.99
Purchased Electricity**	21.50
Purchased Fuels and Electric Energy (Grand Total)	49.49

* "Other" includes "Fuels not specified by kind."[4]

** Purchased Electricity converted at 3413 Btu/kWh; self-generated electricity, representing 1% of the total electricity used, is already included in the individual fuel consumptions above in order to avoid double counting.

Since broad weaving mills manufacturing fabric of primarily man-made fiber and silk solely comprise the industry identified under SIC 2221, the U. S. Census Bureau data reported for this SIC is considered entirely representative of that industry.

3.0 PROCESS ENERGY REQUIREMENTS

The following sub-sections describe the thermal and electrical energy requirements per unit of production for broad weaving mills (man-made fiber). A summary of energy requirements per unit output is presented in Exhibit 2221-4.

3.1 UNIT ENERGY CONSUMPTION DATA

Broad weaving mills are highly diversified in process operations and end products both of which determine the characteristics of energy use. For the production of broad woven fabric of primarily man-made fiber the unit energy requirements as an industry composite from the U.S. Census Bureau energy consumption data for SIC 2221 are shown below:

UNIT ENERGY REQUIREMENTS

BROAD WOVEN FABRIC, MAN-MADE FIBER

	MM Btu/Ton
Electricity*	19.23
Steam**	17.93
Direct Fuel (Natural Gas)	1.73
Total	38.89

* Electricity converted at 3413 Btu/kWh; includes 0.2MM Btu/ton of self-generated electricity.

** Assuming an 80% boiler efficiency, fuel consumed to produce steam represents 22.41 MM Btu/ton.

3.2 DETAILS OF ENERGY CONSUMPTION

Broad weaving mills usually operate 24 hours per day, 6 days per week; however, this schedule is sensitive to market demand and may vary from 5 to 7 days per week.

As mentioned in Section 1.2, there are two forms of broad weaving mills: the greige mill and the integrated mill. Process operations differ between these two types of mills and even between similar type mills depending on the end product. At an integrated mill, finishing operations are sequenced in an order exclusive for the type of product desired. At a greige mill, although process operations may not be as varied and diverse as the finishing operations of an integrated mill, energy consumption is still influenced to a great extent by the end product. For instance, a greige mill weaving a heavier fabric would be less energy-intensive per unit of output because the heavier yarns are thicker, thus requiring fewer warp and filling yarns per unit area and hence, fewer loom operations to produce a fabric with a greater weight per unit area.[5] Overall, it should be noted that the energy consumed by broad weaving mills is highly varied depending on the process operations and equipment, end product (partly dependent on fashion trends), and the extent to which a mill is specialized or diversified.

In the greige mill, steam is required only for drying in the slashing operation whereas an integrated mill uses steam in the finishing operations (as well as slashing) for drying, hot water, and agitation. For all greige mills, steam pressures range between 15 psig to 125 psig, however, steam for slashing is commonly used at 15 psig to 35 psig or 75 psig to 125 psig (the recent trend is for using the higher steam pressures in

order to increase production rates). An integrated mill utilizes steam in the range of 100 psig to 150 psig.

Electricity is used to drive process equipment and provide air conditioning and lighting. Fiber and fabric in process are sensitive to atmospheric conditions such as temperature and humidity. As a result, air conditioning is carefully controlled and can consume between one-fifth to one-third of the total energy in an integrated mill and as much as one-half in a greige mill.(1)(5)

Natural gas is used as a direct fuel for drying (as required after certain wet or washing type finishing operations) and for some finishing operations utilizing it directly (i.e., singeing-burning superfluous fibers off fabric surfaces, etc.). Its direct use is limited only to integrated mills, greige mills do not use any fuel directly. At a griege mill, the comparatively small amount of drying done in the slashing operation utilizes steam.

The relative amounts of energy consumed (as a percent) for typical greige and integrated mills are shown below:

PERCENT RELATIVE ENERGY USE(1)(5)

(Btu Basis)

	Greige Mill		Integrated Mill	
	Typical	Range	Typical	Range
Electricity	85	70-90	50	na
Steam	15	30-10	42	na
Natural Gas	none	none	8	5-15
Total	100%	100%	100%	--

4.0 ANTICIPATED TRENDS

This section discusses trends through the year 2000. Major emphasis is on market development and trends in process technology and energy consumption.

4.1 PRODUCT GROWTH TRENDS

The textile industry has always been characterized by its sensitivity to market demand (fashion trends) and more recently, technological advances. For the broad weaving industry, utilizing primarily man-made fibers, other additional factors have an even more direct effect; together these factors are:

- competition of woven versus knit fabrics. At present, the major advantage for weaving is the greater range of yarns that can be used. Other advantages include production of different cloth widths on the same machine, multiple cloth width weaving, and the use of more than four filling colors.[6]
- competition from imports. By 1990, with the current import of rate of 7%/yr., textile and apparel imports will reach 50% of domestic production versus 24% today.[7]
- fashion trends, pitting natural fibers against synthetics (i.e., cotton vs. polyester).
- environmental and safety regulations (noise reduction, fiber dust elimination, etc.) increasing non-productive costs and reducing available capital for reinvestment.
- technological advances reducing operating costs, increasing production, and creating new fabrics and styles.

Considering the above factors, future trends in the production of broad woven fabric of primarily man-made fibers are difficult to assess. However, on the basis of the 1976 per capita production* of 12.2 lbs. fabric/person applied to the forecast 1985 and 2000 U. S. population[8]

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* In order to avoid the effects of the 1974-75 recession and to remain consistent with previous trends, the 1976 per capita consumption was chosen.

and the linear regression method of extrapolation, two predictions were made and the average between them chosen (Exhibit 2221-5).

PRODUCTION

BROAD WOVEN FABRIC, MAN-MADE FIBER

(millions of pounds)

Historical			Forecast (Average*)	
1975	1976	1977	1985	2000
2,257	2,628	2,716	3,030	3,832

4.2 PROCESS CHANGES AND IMPLEMENTATION OF NEW TECHNOLOGY

Although the textile industry's R&D spending rate is considered low and falling behind other industries,[9] there are several potential process changes being evaluated and several taking place now.

At present, shuttleless looms (rapier, airjet, etc.) are expected to replace the fly shuttle loom at an increasing rate. The shuttleless looms offer higher production rates and greater product diversity enabling manufacturers to keep up with the changing market trends. (Energy savings from these looms are expected to be marginal as their higher production rates have proportionately higher energy requirements.)[1]

Future finishing operations are expected to incorporate techniques to reduce energy consumption in drying. The techniques would mechanically remove a portion of the water (i.e., by squeezing fabric between rolls

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* As mentioned above (Section 4.1), the forecast production is the average of the percapita production applied to the forecast population and the linear regression method of extrapolation:

Method	Forecast Production (MM lbs.) 1985	2000
Per Capita	2,688	3,005
Linear Regression	3,372	4,659

or by water runoff from contacting a roll, etc.), thereby reducing dryer loads. In addition, new finishes and dyes are being formulated which would require less water.(10)

There is also a revival of interest in the use of radiation technology (i.e., electron beam, ultraviolet, etc.) in a variety of finishing operations. Radiation processing offers several advantages: greater efficiency of energy utilization, use of more available electrical energy, and the development of chemical systems to allow a wider variety of treatments.(10)(11)

Finally, weaving mills are expected to diversify, rather than specialize in one product, (as is largely done today) thus improving response to market changes.(1)

4.3 TRENDS IN ENERGY REQUIREMENTS

From the development of an energy conservation target for SIC 22, "Textile Mill Products," the Department of Energy, and the textile industry have adopted an energy conservation goal of 22% by 1980, relative to 1972 usage.(5)

Based on this target and the available energy conservation measures, it was assumed that an equivalent 22% reduction in unit energy consumption across the board for the broad weaving industry (man-made fibers) could be achieved by 1985, relative to 1975. Further, with the advent of developing energy conserving technologies, chemistry, and equipment, an additional 20% reduction in unit energy requirements between 1985 and 2000 is potentially feasible.

The total estimated energy consumption, including a breakdown showing fuel and electric energy consumed, through the year 2000, is presented below.

ESTIMATED ENERGY CONSUMPTION TRENDS, 1975-1985-2000

BROAD WEAVING MILLS, MAN-MADE FIBER

$\times 10^{12}$ Btu	1975	1985	2000
Total Purchased Fuel and Electricity	49.0	51.2	66.5
Purchased Fuel**	27.3	28.5	37.0
Purchased Electricity*	21.7	22.7	29.5

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* Electricity converted at 3413 Btu/kWh.

** Assuming an 80% boiler efficiency, purchased fuel would represent the following steam and direct fuel breakdown.

$\times 10^{12}$ Btu	1975	1985	2000
Steam (@ 75-150 psig)	21.0	21.9	28.4
Direct Fuel (Natural Gas)	1.1	1.1	1.5

5.0 PLANT SPECIFIC DATA

This section provides available data relating to specific plant energy requirements, load profiles, state conditions, and reliability considerations.

5.1 LOAD PROFILES

Broad weaving mills usually operate 24 hours per day, 6 days per week, but vary between 5 to 7 days per week depending on market demand. The electrical load factor for the operating time period is estimated as in excess of 90% and for the off day or shutdown period it is estimated to vary between 6% and 25%.[1] Overall, for the combination of the operating and shutdown time periods, the electric load is estimated as in excess of 75%.

Similarly, the thermal-electrical coincidence factor is estimated as greater than 0.90 for the operating time period and 0.00 for the shutdown period; hence, the combined factor (operating and shutdown periods) is 0.78.

5.2 ENERGY FLOW, MASS FLOW, AND STATE CONDITIONS

As noted in Section 1.2, broad weaving mills are divided into two types; greige and integrated mills. Both use electricity to drive machinery and provide lighting and air-conditioning. However, the relative energy consumed by each type mill differs (Section 3.2) as a result of the different process operations and end products. The integrated mill includes finishing operations in addition to weaving and other preparatory process steps. The finishing operations vary from mill to mill depending on the end product but overall, integrated mills use

significantly more steam than greige mills; approximately 42% versus 15% of the total plant energy, respectively, is common.*(1)(5)

In the greige mill, the steam is used in the slashing operation to heat cylinders ("drying cans") over which the coated ("sized") warp yarns are dryed. Steam is used at pressures ranging from 15 to 35 psig and 75 to 125 psig. The higher pressures are gaining popularity as they are adapted to processes to increase production rates. The integrated mill uses steam in its finishing operations (in addition to slashing). The steam (100 to 150 psig) is primarily used for drying and hot water. (Since most broad weaving mills are located in the south, steam for space heating represents a relatively small quantity of total energy consumption, between 4 and 13%).(5)

Natural gas, as a direct fuel, is used only in integrated mills for drying after certain finishing operations. Its consumption varies between 5 to 15% of the total energy consumed by a mill and 8% is considered typical.*(1)(5)

Broad weaving mills vary in size depending on the end product, market demand and share, type of equipment, location, and economics of scale. Major manufacturers operate mills of considerable size, for example, 500-900 looms. However, mill output may also depend on the type of product and quality of the equipment as well as quantity.

The different types of looms described in Section 1.2 operate at different speeds and are suited for some yarns (lighter or heavier) more than others. For example, the fly shuttle loom typically operates at

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* It should be realized that because of the tremendous diversity in this industry, a "typical" mill is strictly hypothetical.

than others. For example, the fly shuttle loom typically operates at about 180 picks per minute (ppm)* and 1½ to 2 horsepower. The rapier, missle, waterjet and airjet looms operate at typically 250, 300, 500, and 500 ppm respectively, and with increasing horsepower, up to 6-8 hp for the airjet looms.

The preparatory operations (picking, carding, etc.) each have different production rates, also dependent on the fiber or end product. A picking machine can handle between 300 and 600 lbs./hr. as contrasted with a carding machine which can process 5 to 90 lbs./hr. depending on the fiber. A draw frame can process as much as 200 lbs./hr. while a roving frame can run 1 to 10 lbs./hr./spindle with about 96 ends/machine. Two spinning processes are used: ring spinning and open-end spinning. The former runs 1-2 oz./hr./spindle while the latter can produce 7-8 times as much but with a proportionately higher cost. Yarn from each spinning process may or may not be substituted for each other depending on the end use. There are also approximated 2-3 slashers, and 1 bleach and dye ranger per mill of 500 to 900 looms.

Additionally, although greige mills do not finish their product, they are usually located around a central finishing plant which finishes fabric from several greige mills.

5.3 RELIABILITY CONSIDERATIONS

In the broad weaving industry, the process equipment used is not nearly as sensitive to a power failure as is the product.

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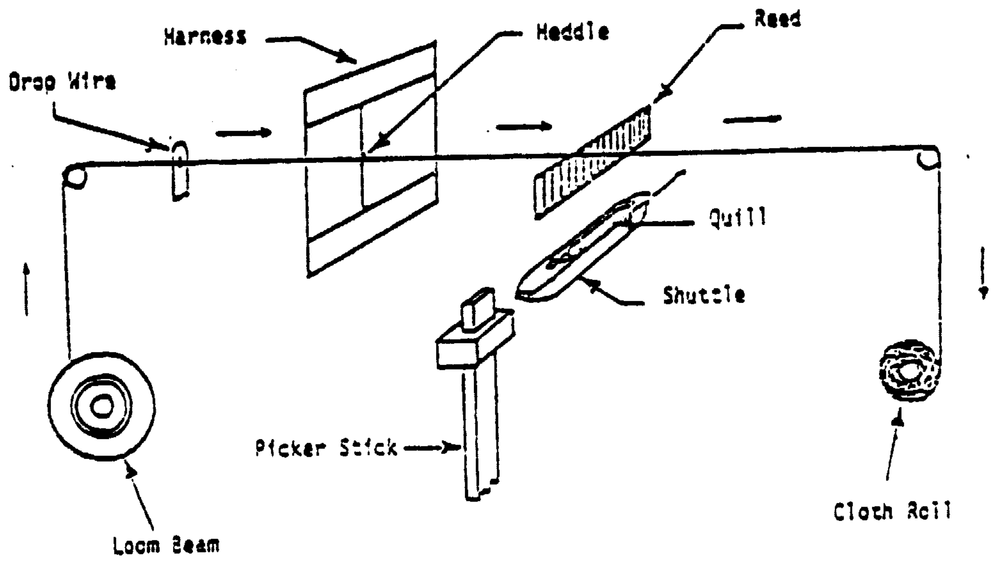
* The weaving speed of a loom is measured as the number of picks per minute (ppm). A "pick" is one thread of filling or one pass of the shuttle across the loom. Hence, the speed with which each filling yarn is inserted is measured as the number of filling yarns inserted per minute or the number of picks per minute.

Following a power failure, a greige mill could start-up in 30 minutes.[1] However, product losses would occur at several process operations. In the spinning operation, yarn would be lost at start-up due to breaks and defects. At the slashers, warp yarns (or beams) interrupted by the power failure would have to be disposed of, as a result of the nonuniform or irregular size (coating) applied upon start-up. Improper slashing can result in warp yarn breaks at the loom, yarns sticking to the beam or adjacent ends, warp streaks, size shedding, balling between the reed and heddle, and brittleness. Finally, fabric on the looms during start-up would show a weaving defect from the initial operation.[1]

A power failure at an integrated mill would result in a lengthier downtime period since, in addition to the greige mill operations affected, finishing operations would also be affected. Many finishing operations are temperature and time sensitive, a power failure would result in a total product loss at these operations. For a power outage of short duration (less than 10 minutes), an integrated mill can resume operation in 1 hour however, a power outage of longer duration (more than an hour), would result in 8-16 hours of downtime.[1]

EXHIBIT 2221-1

BASIC FLY SHUTTLE LOOM ELEMENTS



Drop Wire: one per warp yarn; shuts-off loom if warp yarn breaks.

Heddle: a wire with a loop through which the warp yarn(s) pass.

Harness: a harness holds many heddles, (more than one harness per loom).

Reed: a guide which also "beats" the filling into the "shed" (space between alternately raised and lowered warp yarns).

Shuttle: a projectile carrying the quill (filling yarn) through the warp yarns.

Picker Stick: throws shuttle through the she.

EXHIBIT 2221-2

BROAD WEAVING MILLS, MAN-MADE FIBER PROCESS FLOW DIAGRAM

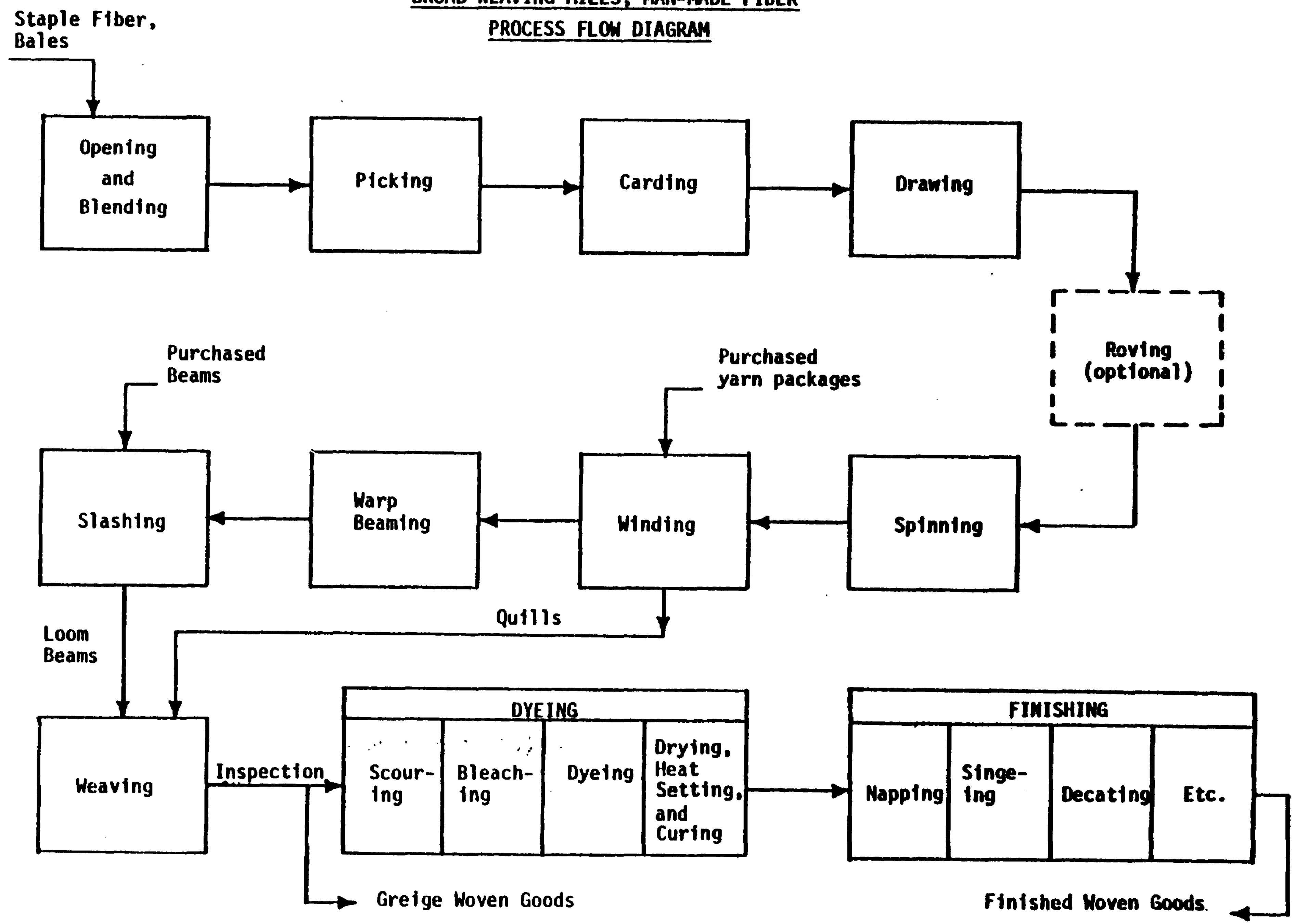


EXHIBIT 2221-3

ANNUAL NATIONAL DATA - 1975

SIC 2221 - BROAD WEAVING MILLS, MAN-MADE FIBER

Product Production Million Tons	Total Energy Consumption Trillion Btu	Purchased* Electricity Trillion Btu	Purchased Fuels Trillion Btu	Coal	Oil	Gas	Other	Total Energy Consumption For SIC Trillion Btu	Percent Total Energy Consumption Represented
1.13	49.49	21.50	27.99	6.23	8.50	11.26	2.00	49.49	100%

* Electricity converted at 3413 Btu/kWh.

EXHIBIT 2221-4

Energy Consumption Per Unit Output: Broad Weaving Mills, Man-Made Fiber

Electricity* Million Btu Per Ton	Hot Water Million Btu Per Ton	Steam** (Million Btu Per Ton)			Direct Fuel(1) Million Btu Per Ton	Exhaust Stream	
		To 300° F	300-500° F***	Over 500° F		Temperature °F	Energy Million Btu Per Ton
19.23	--	--	17.93	--	1.73	--	--

* Electricity converted at 3413 Btu/kWh.

** Assumes an 80% boiler efficiency.

*** Although a small portion of steam is used at 15-35 psig (below 300° F) in some greige mills, the majority of all mills, greige and integrated, use steam in the 300-500° F category.

NOTE: The above data is representative of the industry as a whole and is not specific for a type of mill (i.e., greige or integrated mills) but rather the combination of all mills within SIC 2221.

EXHIBIT 2221-5

BROAD WOVEN FABRIC, MAN-MADE FIBER

PRODUCTION

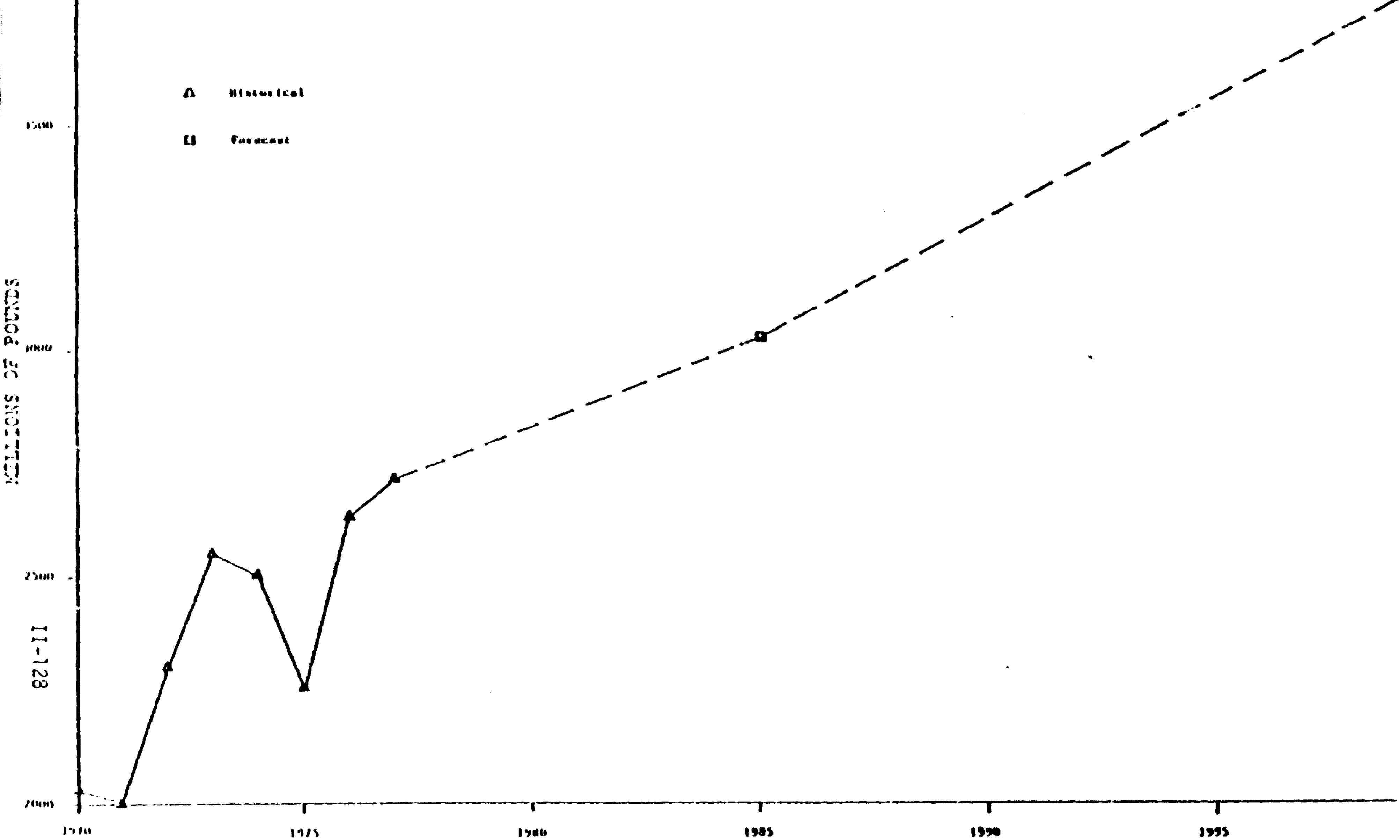


EXHIBIT 2221-6

BROAD WEAVING MILL FACTORS

Typical Plant Capacity Tons/year	Plant Size Range Tons/year	Electric* Load Factor	Thermal Electrical Coincidence Factor	Projected Applicability To 2000
6,000	4,000-12,500	> 75%	0.90-1.0	Good

* Broad weaving mills usually operate 24 hours/day, 6 days/week and sometimes vary between 5 to 7 days/week depending on market demand. For the 6 day period the electrical load factor is estimated as in excess of 90% and for the 1 day shutdown period is estimated to vary between 6% and 25%.(1) The above electric load factor is estimated for the 7 day week, the combination of the operating and shutdown periods.

FOOTNOTES

(1) Private communication with industry representatives.

(2) American Textile Manufacturers Institute, Inc., "Textile Hi-Lights," June 1978.

(3) Textile Economics Bureau, Inc., "Textile Organon," Vol. 49, No. 2, February 1978.

(4) U.S. Department of Commerce, Bureau of Census, "Annual Survey of Manufactures, Fuels and Electric Energy Consumed," 1975.

(5) SCS Engineers, Inc., "Energy Efficiency Improvement Target in the Textile Mill Products Industry, SIC 22," Federal Energy Administration, June 1976.

(6) Textile Industries, November 1975, pp. 57.

(7) Textile World, March 1978, pp. 43.

(8) U.S. Department of Commerce Bureau of Census. The U.S. Fact Book, The American Almanac for 1978, 98th edition, October 1977.

(9) Textile World, January 1978, pp. 53.
Daily News Record, Fairchild Publishing, New York, February 13, 1976, pp. 13.

(10) Textile Industries, October 1977, pp. 37, 39.

(11) Textile Industries, May 1975, pp. 99, 104, 106.

SAWMILLS

1.0 PROCESS IDENTIFICATION

This section identifies the SIC classification for sawmills and provides a description of their manufacturing process.

1.1 SIC Classification

Those establishments primarily engaged in sawing rough lumber and timber from logs and other unfinished forms of wood are classified under SIC 2421, "Sawmills and Planing Mills, General". Planing mills combined with sawmills, as well as separately operating planing mills primarily engaged in producing surfaced lumber and standard patterns of lumber are also classified under this SIC. Logging camps combined with sawmills, when not separately reported (in SIC 2411), are included in this industry.

1.2 Process Description

The sawmilling industry is comprised of three distinct manufacturing plants operating independently or together on one common site. They are:

1) saw mills
2) kiln drying plants
3) planing mills

There are more than 1,600 mills in the U.S.[1] Some are satellite mills serving a common drying and planing mill; others just produce rough (unplaned) air dried lumber. The most common form, characteristic of the larger mills, is the combination of the sawmilling, kiln drying, and planing operations into one manufacturing complex.

Sawmills cut logs into rough lumber or timber; they may be divided by type into dimension lumber mills or stud lumber mills*. The basic

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* Dimension lumber mills primarily produce boards (plus some other patterns) of standard or common dimensions. Stud mills primarily cut studs (i.e., building lumber, usually 2 by 4 inches and 8 to 10 feet long).

difference between these two mills is in the log cutting pattern, lumber drying and finishing, and the quantity and type of by-product (chips, sawdust, etc.).

In preparation for cutting the log must be debarked. This prevents blunting the saws from small stones and grit picked up during the transport to the mill and allows for the sale of offcuts for pulping. The most common method of debarking uses jets of high pressure water; another method employs a mechanical rotary debarker using knives. After debarking, the log is mechanically conveyed to the carriage, a platform which carries the log through the headsaw*. The band saw is the most widely used saw for breaking down logs in large sawmills. A band saw consists of a continuous band of steel with teeth on one or both edges, mounted on two large wheels (up to 6 feet in diameter), one of which is above and one below the cutting area. Power is applied to the lower, heavier wheel as the log is fed on the carriage. Band saws have an advantage over circular saws because they have a narrower kerf**, thus reducing the loss of wood as sawdust. (Circular saws are more common in small to medium size mills, especially stud mills.) At some mills, a band resaw (either vertical or horizontal) follows the headsaw to assist in log breakdown. After the headsaw (or resaw), the boards are conveyed to the edger. The edger, a set of smaller saws (circular), trims the rough edges from each board and makes the sides straight and even. Next, the edged boards go to a trimmer. This set of saws makes the ends of the boards square, and cuts the boards to the

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* Some mills use a chipping headrig integrated with the headsaw. The chipping headrig converts the outside "slabs" of the log into chips as it is cut on the headsaw. The chips may be used for pulping.

** Kerf - width of the cutting blade; wider blades produce more waste or sawdust.

exact lengths desired. These edged and trimmed boards are the final product from the sawmill and can now be dried.

Drying (or seasoning) removes excess moisture from the wood under controlled conditions, thus preventing warping. Air drying is done by stacking the wood outdoors and allowing the sun and wind to dry it. Depending on the wood, its thickness and climatic conditions, air drying can take from 20 days to one year. Kiln drying facilitates the removal of moisture from the green lumber by increased temperature and controlled humidity. Kiln drying usually takes 1 to 2 days, however, depending on the thickness of the wood, it can take up till one week. In kiln dryers, steam is used to control temperature and humidity and electric fans provide air circulation.

After drying, the rough (undressed) lumber may be sent to the planing mill. The lumber is surfaced to a smooth finish by the planer, then graded, retrimmed, sorted, stacked, and strapped into the final package form.

A schematic outlining the process flow is shown in Exhibit 2421-1.

2.0 NATIONAL DATA

The annual national data for the sawmill industry is presented in this section. A summary of energy consumption and production is shown in Exhibit 2421-2.

2.1 Production Data

Summarized below is the total U.S. production of lumber for 1974 through 1977.

Production[2]
(Million Board Feet*)

	1974	1975	1976	1977
Total Softwoods	27,688	26,215	30,030	31,718
Total Hardwoods	6,904	5,872	6,442	6,188
Total Lumber	34,592	32,087	36,472	37,906

There are over 1,600 sawmills in the United States. They range in size from a few hundred board feet per year to 200 million board feet per year. The majority of mills fall between 8.5 and 13.0 million board feet per year with 12.0 million board feet per year considered typical[3]. The results of a survey of 1,667 companies accounting for 84% of the industry's production in 1977 is shown below.[1]

United States - 1977
(million bd. ft.)

Production Range	Number of Mills	Production
50 MM and up	186	14,675
25-50 MM	229	8,402
10-25 MM	338	5,411
5-10 MM	277	1,936
3- 5 MM	220	840
Other	417	576
Totals	1,667	31,840

* The board foot is the standard unit of measure for lumber; it is a piece of lumber 1 foot long, 1 foot wide, and 1 inch thick.

The mills accounting for the remaining 16% of the annual production are exceptionally small in size, great in number, and transient as to their stability in the market. The top 10 U.S. companies are shown below:

Top 10 Lumber Producers - 1977[1]
(million bd. ft.)

		Number of Mills*	Production*
1)	Weyerhauser Co.	23	2,393
2)	Louisiana-Pacific Corp.	57	1,796
3)	Georgia-Pacific Corp.	45	1,292
4)	Boise-Cascade Corp.	24	823
5)	Champion-International Corp.	18	813
6)	Polatch Corp.	12	674
7)	Publisher Paper Co.	7	563
8)	Crown Zellerbach Corp.	8	557
9)	International Paper Co.	12	535
10)	St. Regis Paper Co.	8	468

2.2 Annual Energy Consumption

The U.S. Census Bureau reports the following energy consumption by fuel type for SIC 2421 in 1975:[4]

1975 Annual Energy Consumption, SIC 2421

Energy Source	Consumption(x 10^{12} Btu)
Fuel Oil	10.69
Coal	****
Natural Gas	19.35
Other**	****
Purchased Fuel(total)	50.51
Purchased Electricity***	21.50
Purchased Fuels and Electric Energy(grand total)	72.01

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* Includes only data specific for the United States even if the companies listed may have mills operating in Canada.

** "Other" includes "fuels not specified by kind".[4]

*** Purchased electricity converted at 3413 Btu/kWh; self-generated electricity, only 3.4% of the purchased electricity, is already included in the individual fuel consumptions above in order to avoid double counting.

**** Coal and other purchased fuels were not revealed by the 1975 Census[4] in order to avoid disclosing figures for individual companies.

From the 1974 Annual Survey of Manufactures, approximately 33% of the total purchased fuel (on a Btu basis) is consumed under the categories of "Other Fuel" and "Fuels not specified by kind"(5). Since the sawmill industry comprises the entire industry identified under SIC 2421, the above percentage can be used in combination with the 1975 Census data(4) to estimate energy use by fuel type for the industry.

1975 Annual Energy Consumption - Sawmills

Energy Source	Consumption($x10^{12}$ Btu)
Fuel Oil	10.69
Coal*	3.80
Natural Gas	19.35
Other	16.67
Purchased Fuel(total)	50.51
Purchased Electricity**	21.50
Purchased Fuel and Electric Energy(grand total)	72.01

* Coal consumption was estimated by difference.
** Converted at 3413 Btu/kwh.

3.0 Process Energy Requirements

The following subsections describe the thermal and electrical energy requirements per unit of production for the sawmill industry. A summary of the energy requirements per unit output is presented in Exhibit 2421-3.

3.1 Unit Energy Consumption Data

As mentioned in section 1.2, the sawmill industry employs three distinct processing operations: sawing rough lumber, kiln drying, and planing. Typically, for the major mills, these operations are integrated into one plant complex. However, as is evidenced by the large number of mills (more than 1600), many mills deviate from this form. They operate as sawmills with or without kiln drying or planing and they are usually small in size. In addition, although mill operations are the same throughout the industry, the varying degrees of mechanization, as well as the type of wood (soft or hard wood), can affect the overall production efficiency.

Hogged fuel (sawdust, shavings, bark, etc.) generated from the sawing and planing operations is typically burned as boiler fuel (to raise plant steam). With an average 25% and 40% of the log volume as waste fuel (sawdust, shavings, etc.), and dressed lumber, respectively,[3] the hogged fuel* steam contribution (at 60% boiler efficiency) is estimated as 9 million Btus of steam per thousand board feet of dressed lumber. However, since only approximately 65% of all the hogged fuel generated is

* Hogged fuel energy equivalent: 18 MM Btu/ton [6] (or approximately 0.288 MM Btu/ft^3 = 0.024 MM Btu/bd. ft.)

burned (the remainder is sold), an estimated 5.85 MM Btu/1000 bd. ft. is contributed to the unit energy requirements derived for the industry as a whole. This is illustrated below.

Unit Energy Requirements - SIC 2421
(1975 - Industry Composite)

	MM Btu/ 1000 Board Foot
Steam (derived from fossil fuel)*	1.50
Steam (derived from hogged fuel)**	5.85
Steam, Total	7.35
Electricity***	0.69
Total Energy	8.04

3.2 Details of Energy Consumption

The integrated sawmill complex operates on three different schedules, one for each operation. Besides kiln drying which operates 24 hours per day, 7 days per week, the sawmill and planer mill operate 2 shifts per day and 1 shift per day, respectively, both 5 days per week. The sawmill prepares the wood into an easily processable form for the planer mill. The planer mill, usually more automated, has a higher throughput and shorter operating schedule.

Electrical energy consumption is comparatively small at the integrated mill. This is primarily due to the shorter operating time and lower energy requirements characterizing the sawmilling and planing operations, relative to kiln drying. Electrical requirements are for driving the automated electrical equipment such as bandsaws, edgers, trimmers, planers, conveyors, hoists and debarkers. In addition, it is also used for lighting, log scanning computers (which aid in finding the best sawing pattern), and for driving the fans and instrumentation in the kiln dryers.

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* Derived from fuel at 80% boiler efficiency.
** Derived from hogged fuel at 60% boiler efficiency.
*** Converted at 3413 Btu/kWh.

The kiln dryers are steam heated, and no fuel is used directly. Steam is used to create drying temperatures in the kiln commonly ranging from 180°F to 240°F. Some of it is passed through a heat exchanger and some is used in the kiln atmosphere for humidity conditioning, hence, only 70% is recoverable.[7] At the kiln, steam is used at pressures ranging from 80 to 100 psig.

4.0 Anticipated Trends

This section discusses trends through the year 2000. Major emphasis is on market development and trends in process technology and energy consumption.

4.1 Product Growth Trends

Timber and wood products demand has historically been tied to the number of housing starts.(8) Softwood lumber, representing 84% of the total lumber production, is the wood most used in home building and other construction as shown below.

U.S. Softwood Lumber Consumption - 1977*

Market	Percent
Residential building	46
Other new construction	14
Repair and remodeling	20
Materials handling	10
Other	10
Total	100

Another important factor in the lumber industry is the availability of raw forest products. In the West, the national forests are the major single source of timber supply (the Forest Service is a monopoly owner and seller of timber).(8) National forests supply 15% of all the timber consumed annually in the U.S., 27% of all the U.S. softwood saw timber harvested annually, and own 52% of the nation's total inventory of standing softwood sawtimber.(8) Presented below is a breakdown of softwood sawtimber inventory and harvest by government, public, private, and industrial sectors.(8)

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* Western Wood Products Association

1977	Standing Softwood Sawtimber Inventories	Softwood Sawtimber Harvest
National Forests	52%	27%
Nonindustrial Private	20%	30%
Forest Industry	16%	34%
Other Public	12%	9%

According to the U.S. Department of Commerce, lumber production in 1982 should total 41.5 billion bd. ft. versus the 38.8 billion bd. ft. estimated for 1978. This implies an annual growth in the neighborhood of 1.7%, which may be extrapolated to show a total lumber production of 43.7 billion bd. ft. in 1985. In addition, the Forest Service projects the U.S. demand for timber products will double by the year 2020 and the 1975 Resources Planning Act projects housing starts in the year 2000 to show an average growth rate of 1.26% per year from 1978. If lumber production were assumed to grow proportionately between these two projections, the lumber production in the year 2000 may be estimated at 55.1 billion bd. ft. ± 10%. A graph of lumber production to the years 1985 and 2000 is shown in Exhibit 2421-4.

4.2 Process Changes and Implementation of New Technology

Technological advances in the sawmill industry are characterized by innovation and invention to increase throughput and optimize lumber recovery. Sawmills are becoming increasingly more automated. Of growing popularity is the use of an optical scanner at the headsaw. The optical scanner measures the log and determines the best sawing pattern for the type of lumber it was programmed to produce, thus maximizing lumber recovery. It is also used to determine the optimum orientation of crooked logs before they go through the headsaw. Another development finding increasing use in sawmills is the "chipping-headrig." It converts the outside "slabs"

of the log into chips as the log is sawn into lumber. Operation is continuous, throughput is high, and the by-product chips are sold as raw material for pulping.

In past years, wood waste was burned wastefully. Now, with the high cost of energy plus environmental laws against such wood incineration, hogged fuel has taken on a higher value. For those large mills which can afford the high capital cost of a wood waste boiler, hogged fuel is being salvaged as boiler fuel to raise steam for the dry kilns or, as in one sawmill,* for cogeneration. (Small sawmills sell the waste wood as fuel).

Finally, the recent development of a solar kiln dryer which can supply 40% of the heating requirements from the sun's energy, is yet to be accepted by industry.[9]

4.3 Trends in Energy Requirements

Because SIC 2421 does not rank among the largest energy consumers in the U.S., the Federal Energy Administration did not require that an energy conservation "target" be set for the sawmill industry. Furthermore, little has been published relating to energy-conserving innovations likely to take place in this industry in the future. For these reasons, estimation of quantitative levels of energy consumption through 2000 is difficult.

It may be expected that, due to the rising cost of energy, this industry will follow suit with most other industries in the U.S. by

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* Georgia-Pacific Corp.'s Fort Bragg, California lumber sawmill cogenerates (with hogged fuel) supplying the large surplus of electric power to their adjacent pulp and paper mill.

taking steps to reduce its energy needs. The primary activity likely to take place involves housekeeping-type measures. This includes reassessing lighting and space conditioning needs, repairing and improving insulation, repairing or improving steam traps, steam leaks, etc. This phase generally involves relatively small expenditures to achieve gains. A 5 to 10% improvement in energy utilization is typically achieved as a result of this type of program.

The second energy conservation phase includes short to medium range programs involving operations or process improvements. These may include, for example, installing heat recovery exchangers, increased recovery of by-product fuels, improved instrumentation, etc. Another 5-8% improvement can be achieved through these second phase programs.

In the third phase, we are concerned with long range programs, generally involving new processes or major changes to existing ones, and major capital expenditures. These round out to total achievable energy conservation goals to about 25%, in general.

Based on this rather general argument, energy conservation on the order of 25% relative to 1975 levels may be expected in this industry by 2000. By 1985, reductions in energy usage of perhaps 14% are likely. These reductions will probably be spread proportionately among the energy sources presently employed.

The unit energy requirement for sawmills in 1985 and 2000 are presented below.

Unit Energy Requirements, 1975-1985-2000

Million Btu/1000 bd. ft.	1975	1985	2000
Total	8.04	6.91	6.03 ± 10%
Steam (@ 80 to 100 psig)	7.35	6.32	5.51 ± 10%
Electricity	0.69	0.59	0.52 ± 10%

5.0 Plant Specific Data

This section provides available data relating to specific plant energy requirements, load profiles, state conditions, and reliability considerations. Several plant factors are summarized in Exhibit 2421-5.

5.1 Load Profiles

The integrated sawmill complex (sawing, kiln drying, and planing) operates with three different schedules. The sawmill and planer mill both operate 5 days per week on 2 shifts per day and 1 shift per day, respectively, while kiln drying operates 24 hours per day, 7 days per week. During the operating period (5 days of the week), the electric load factor for the integrated sawmill is estimated as in excess of 80%[7]. However, because electric fans operate in the kiln dryers and electric power is necessary to maintain control on the boilers, the electric load factor for the shutdown time period (2 days of the week) is estimated at 20%.[7] Overall, for the 7 day week, the combination of operating and shutdown periods, the electric load factor is estimated at 65%.

Kiln drying, although primarily a steam consumer, requires electric power to drive fans and maintain boiler controls. As a result, even when the sawing and planing operations are shutdown the electrical-thermal coincidence factor remains between 0.90 and 1.0.

5.2 Energy Flow, Mass Flow, and State Conditions

As noted in sections 3.1 and 3.2, the integrated sawmill uses primarily steam and comparatively little electricity (on a Btu basis). Kiln drying which operates 24 hours per day, 7 days per week, is the

primary steam consumer. The sawing and planing mills, primarily electrical in operation, consume the majority of the total required electrical power. For a great many of the sawmills, especially those located in the Northern U.S., power consumption is subject to seasonal variation. As a result of winter temperatures, frozen logs and lumber increase the electrical (sawing) requirements and kiln drying requirements (longer drying time).

From the debarker to the planer production efficiency increases as the wood becomes more processable after each operation (sawing, edging, trimming, drying, planing). Increased mechanization has created higher throughputs but factors such as log diameter and saw kerf have a significant effect on throughput at the headsaw. Blades with large kerfs are more wasteful but allow for greater throughputs, on the other hand, logs of larger diameters are slower to saw through. Head saw feed rates operate at maximum and vary from 70 ft./min. to 350 ft./min. depending on the type of saw and log diameter.[3] Although great variation exists, the following percentages of lumber and residue recovery (based on true log volume) for a bandsaw mill are approximate.[3]

Lumber and Residue Recovery[3]
Bandsaw Mill
(Percentages based on true log volume)

Type of Logs	Random
Dry sawn lumber	(55.4)
Dry dressed lumber	39.9
Chips*	21.7
Sawdust**	18.7
Shavings**	15.5
Shrinkage***	4.2
	100.0%

* Chips - usually sold for pulp.
** A total 25/34.2 percent (sawdust plus shavings) is typically recovered as hogged fuel.
*** Shrinkage - from kiln drying.

Kiln dryers typically operate between 180°F to 240°F using steam in the range of 80 to 100 psig. Since some of the steam is used for humidity conditioning in the kiln atmosphere, only 70% is recoverable.[8] Kiln drying usually takes 1 to 2 days, however, depending on the thickness of the wood, it can take up to one week.

5.3 Reliability Considerations

With the exception of lost production time, the consequences of a power failure at an integrated sawmill are not serious.

Since product and electrical equipment are not sensitive to in-process interruptions, operation could resume within 10 minutes without damage to equipment (debarkers, saws, planers, etc.), or product. In addition, when drying conditions are restored (about 1 hour), kiln dryers can complete drying schedules where they left off and without damage to themselves or the product.

EXHIBIT 2421-1

SAWMILL OPERATIONS - PROCESS FLOW SCHEMATIC

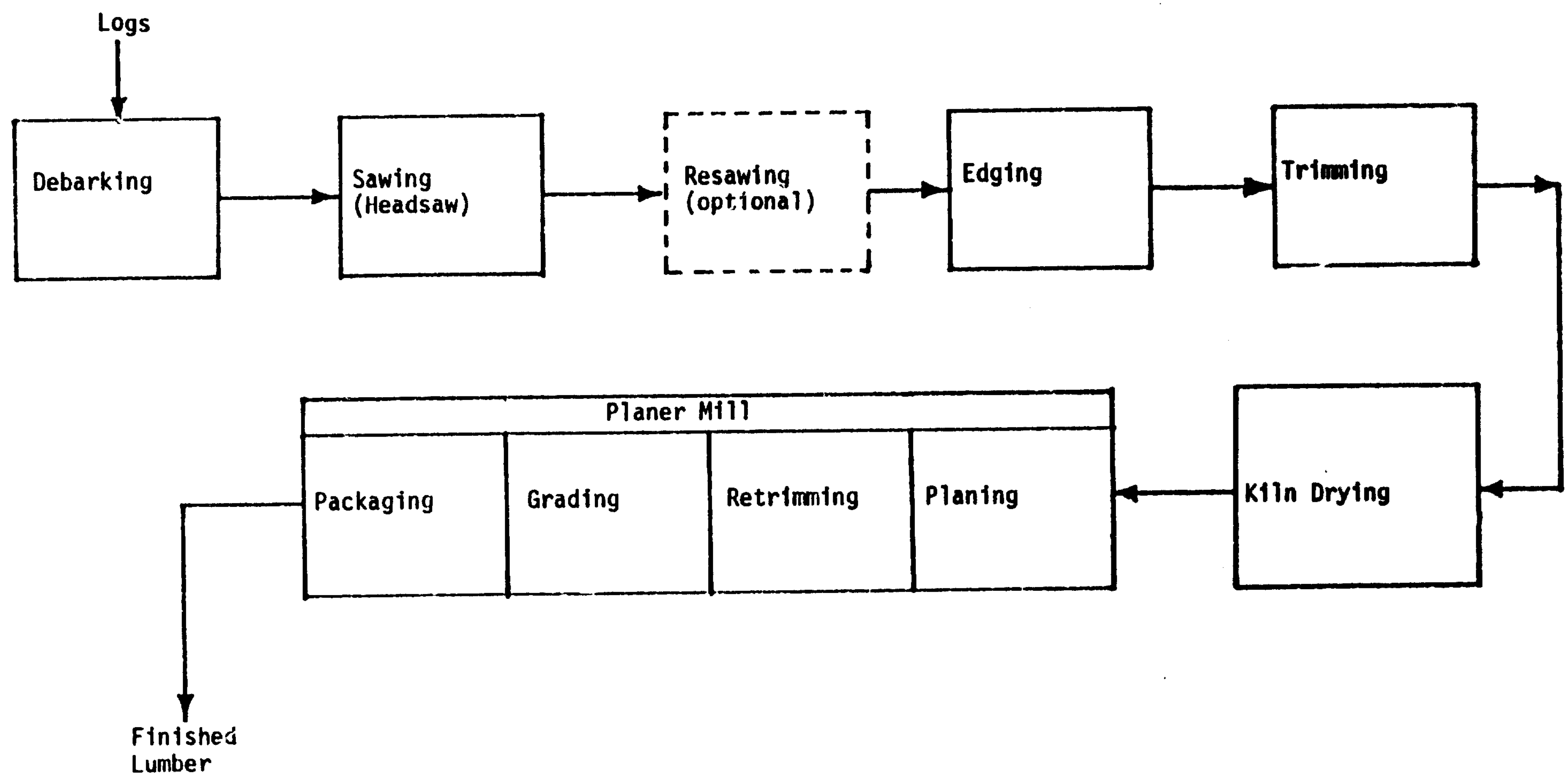

EXHIBIT 2421-2

ANNUAL NATIONAL DATA (1975), SIC 2421 - SAWMILLS

Product Production Million Board Feet	Total Energy Consumption Trillion Btu	Purchased** Electricity Trillion Btu	Purchased Fuels Trillion Btu	Coal*	Oil	Gas	Other*	Total Energy Consumption for SIC Trillion Btu	Percent Total Energy Consumption Represented
32,087	72.01	21.50	50.51	3.80	10.69	19.35	16.67	72.01	100%

* Since "Other" and "Coal" was not revealed by the 1975 Census[4] in order to avoid disclosing figures for individual companies, they were determined using proportions from the 1974 Census[5] (See Section 2.2).

** Converted at 3413 Btu/kWh.

EXHIBIT 2421-3

ENERGY CONSUMPTION PER UNIT OUTPUT: SAWMILLS

Electricity* Million Btu Per M Bd. Ft.	Hot Water Million Btu Per M Bd. Ft.	Steam** (Million Btu Per M Bd. Ft.)			Direct Fuel Million Btu Per M Bd. Ft.	Exhaust Stream	
		to 300^{o} F	$300\text{-}500^{o}F$	Over $500^{o}F$		Temperature ^{o}F	Energy Million Btu Per M Bd. Ft.
0.69	--	--	7.35	--	--	--	--

* Converted at 3413 Btu/kWh

** Derived from total fuel use (assuming an 80% boiler efficiency) and from hogged fuel use (assuming a 60% boiler efficiency).

Notes "M Bd. Ft." is an abbreviation for "1000 Board Feet."

EXHIBIT 2421-4

LUMBER PRODUCTION

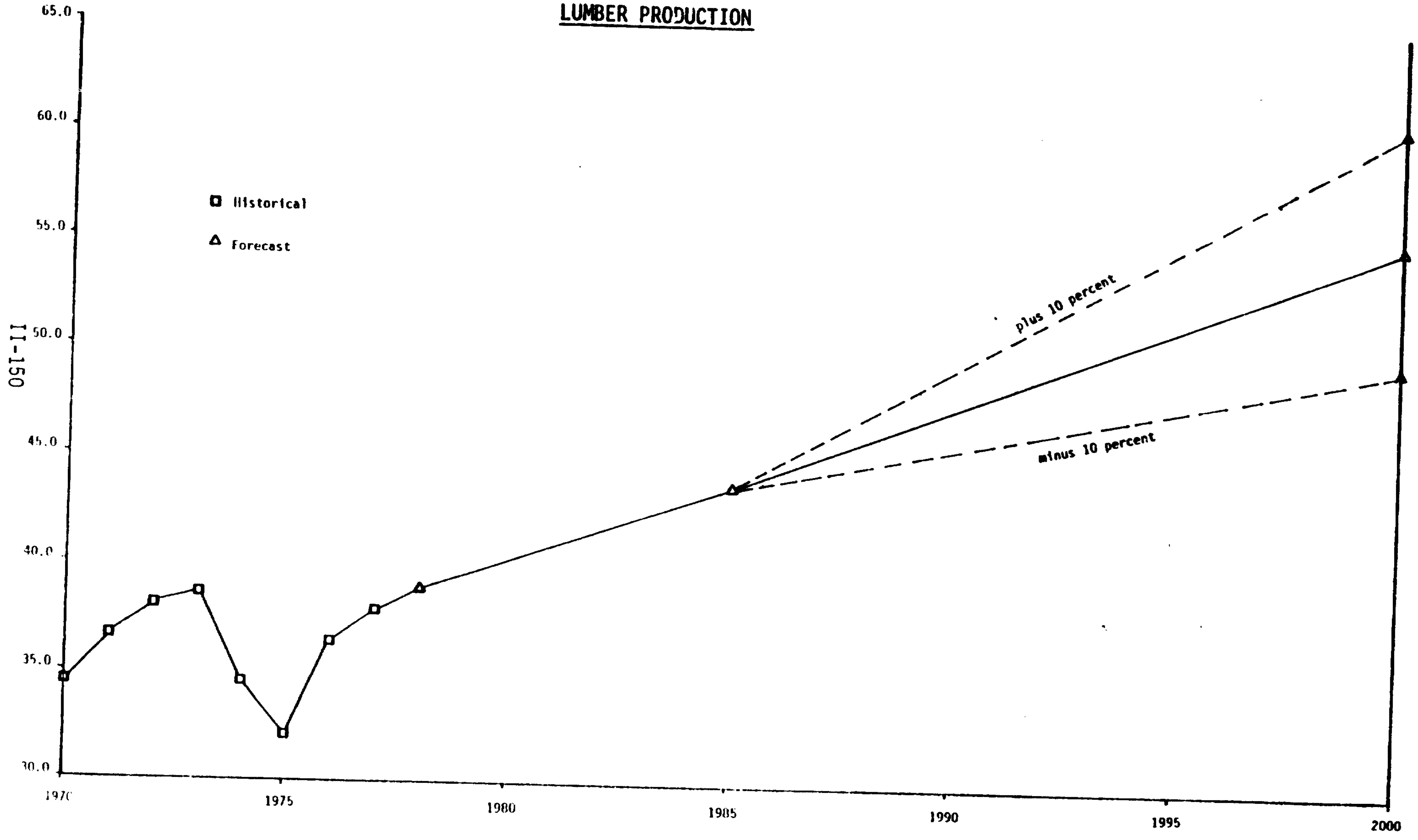

EXHIBIT 2421-5

SAWMILL PLANT FACTORS

Typical Plant Capacity Bd. Ft./Year	Plant Size* Range Bd. Ft./Year	Electric** Load Factor	Thermal Electrical Coincidence Factor	Projected Applicability to 2000
12 million	< 200 million	65%	0.90-1.0	Good

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* Mill sizes range from a few hundred board feet per year to 200 MM board feet per year.

** Integrated sawmills operate with three different schedules; the sawmill and planer mill, both 5 days/week, operate at 2 shifts/day and 1 shift/day, respectively; the kiln dryers operate 24 hours/day, 7 days/week. For the operating period (5 days of the week) and shutdown period (2 days of the week), the electrical load factors are 80% and 20%, respectively.(7) Overall, for the 7 day week, the combination of the operating and shutdown periods, the electric load factor is estimated at 65%.

REFERENCES

(1) "Forest Industries, Annual Lumber Review and Buyers' Guide - 1978", Miller Freeman Publications, San Francisco, Calif., Vol. 105, No. 6, May 30, 1978.

(2) National Forest Products Association, Washington, D.C.

(3) Nordic and North American Sawmill Techniques, Miller Freeman Publications, San Francisco, Calif., June 1975.

(4) U.S. Department of Commerce, Bureau of Census, "Annual Survey of Manufactures, Fuels and Electric Energy Consumed", 1975.

(5) U.S. Department of Commerce, Bureau of Census, "Annual Survey of Manufactures, Fuels and Electric Energy Consumed", 1974.

(6) Ford, Bacon, and Davis, Inc., "Energy Efficiency Improvement Target in the Paper and Allied Products Industry (SIC 26)", Federal Energy Administration, 1976.

(7) Private communication with industry representatives.

(8) Wilderness Withdrawals and Timber Supply, National Forest Products Association, Washington, D.C., July 20, 1978.

(9) "Lumber Kiln Uses Solar Dryer", Energy User News, Fairchild Press, New York, March 20, 1978, page 11.

SELECTED PAPER AND PAPER BOARD PRODUCTS

1.0 STUDY PLAN - PULP AND PAPER INDUSTRY

This section is concerned with the products and manufacturing processes of the pulp and paper industry. The industry is highly complex and diversified and employs a large number of manufacturing techniques for the production of more than two thousand primary products. To a considerable extent, a common sequence of production steps is employed in producing a large majority of different products, although in many cases similar products are produced by alternative process techniques. While it is not possible to explore in detail the processes and energy requirements for a large number of different products, it is feasible to select several examples of paper and paperboard products accounting for a large percentage of all pulp and paper industry products and to examine them in detail with respect to energy requirements. This is the plan in the present study. Four different products, two paper and two paperboard products, which typify pulp and paper industry processing and process energy requirements, are selected for detailed examination.

1.1 SIC Classification

The broad activities of the pulp and paper industry are classified under SIC Major Group 26 - Paper and Allied Products[1]. Subclassifications

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1 "Standard Industrial Classification Manual, 1972," Executive Office of the President, Office of Management and Budget, U.S. Government Printing Office, Washington, D.C.

within SIC 26 are based on the types of products produced and the raw materials used to manufacture products[1].

- Pulp Mills - SIC Group No. 261. These establishments primarily produce pulp from wood or other materials such as rags, linters, waste paper, and straw, for subsequent manufacture of paper and paperboard products. Pulp mills essentially produce market pulp for sale and do not manufacture paper or paperboard or converted products.

- Paper Mills - SIC Group No. 262 and Paperboard Mills -SIC Group No. 263. These establishments produce paper or paperboard for sale to converters, and may themselves manufacture converted paper or paperboard products. These mills are fully integrated with pulp mills producing pulp from virgin wood or other fibrous materials. These mills may produce and sell market pulp in excess of the pulp required for onsite manufacture of paper or paperboard and converted products.

- Converted Paper and Paperboard Products - SIC Group No. 264. These establishments produce a variety of paper (mainly) and paperboard products (except containers or boxes) from purchased paper.

- Paperboard Containers and Boxes - SIC Group No. 265. Establishments within this group produce a variety of paperboard products, specifically identified as containers and boxes, from purchased paperboard.

- Building Paper and Building Boardmills - SIC Group No. 266. Establishments engaged in producing paper and board for the building trades. These mills are largely integrated with pulp mills producing pulp from wood and other fiber sources.

Selected for detailed examination are two paper products, newsprint and writing paper, and two paperboard products, corrugated containers and folding boxboard. In order to adequately display the entire production sequence, it will be assumed that all four products are manufactured in paper and paperboard mills integrated with pulp mills and that each is

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1 Provided here are informal definitions of SIC classifications of industry groups within SIC Major Group 26. For formal definitions, and particularly for extensive lists of products within each SIC classification, the SIC Manual should be referred to.

produced from virgin wood fiber sources. These products have 4 digit SIC classifications as follows:[1]

Product	SIC No.
Newsprint	2621
Writing Paper	2621
Corrugated Containers	2631
Folding Boxboard	2631

Specific characterizations of each of these selected products is offered below using definitions suggested by the American Paper Institute (API)[2].

1.2 Process Description

Virtually all paper and paperboard products are manufactured in the sequence of process steps enumerated below:

1. Pulp wood acquisition; harvesting of forest round wood and procurement of sawmill residues (chips)
2. Debarking of roundwood
3. Chipping of debarked roundwood
4. Pulping; either chemical or mechanical or both
5. Pulp bleaching
6. Paper and paperboard production
7. Converting

Steps 1 - 5 are the primary function of the pulpmill and constitute the SIC definition of Industry 2611. Paper and paperboard production, step 6, can be done in conjunction with the pulpmill (which is then designated an integrated mill), or paper and paperboard can be manufactured with

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1 With the exception of newsprint, the other products shown are often manufactured from purchased paper and paperboard. In these cases the SIC classifications would be as follows:

Product	SIC No.
Writing Paper	2648
Corrugated Containers	2653
Folding Boxboard	2651

2 "Paper, Paperboard, Woodpulp, 1976-1979 Capacity", pp. 28-29 American Paper Institute, New York, 1977.

purchased dried pulp. Converting, step 7, is the process of producing finished paper and paperboard goods. This step can be integrated with paper and board production or can be done using purchased paper and paperboard.

Exhibits 26-1 through 26-4 are flowsheets of the production sequences used to manufacture the four example products selected for this study. An examination of these exhibits reveals that the production of the four selected products generally follow the sequence of steps suggested above with, however, some notable exceptions. For example, the pulp used for the production of linerboard and corrugating medium is not generally bleached, the vast majority of corrugated container products having the natural brown color of the pulped wood. Also, not all roundwood is chipped prior to pulping; groundwood pulping can accept roundwood as well as chips for the pulping process. Only the major process steps are shown on the flowsheets for the products. Not specifically shown are auxillary processes related to the major sequence such as pulp washing and stock preparation (beating, refining and blending), and finishing operations such as calendaring and coating.

The flowsheets shown contain material and energy requirements for each of the major process steps required for the production of the four selected representative products of the pulp and paper industry. The material and energy data shown represent average industry requirements and are not specific for any particular mill. A brief review of the major process steps is offered below.

Pulp Wood Acquisition. Roundwood consists of harvested trees that have been delimbed but with the bark still intact. Sawmill residues are principally chips and shavings which are the byproducts of lumbering

operations. A few saw mills utilize other lumber wastes such as sawdust and large limbs. The proportion of chips to roundwood used at a particular mill depends on the mill location. For example, the major source of virgin wood for pulping in the northwest is in the form of chips resulting from lumbering wastes. As explained below, there are significant energy implications associated with the use of roundwood compared with chips. Also, the pulp and paper industry is increasing its use of forest residues (tree limbs, stumps, undersized trees) as a source of energy in the form of hogged wood which is burned in combination boilers to produce steam and to cogenerate electric energy. In 1972, hogged wood accounted for about 2.1% of the total U.S. pulp and paper industry's energy needs. On a regional basis, the large lumbering operations in the Pacific Northwest supplied the area's pulp and paper industry with almost 9% of its fuels in the form of hogged wood. By 1976, the API estimates that 2.7% of national pulp and paper industry energy needs were supplied by hogged wood and more than 11% of the industry's needs in the Pacific Northwest.

Wood Preparation. Two procedures are involved in the preparation of wood for pulping: debarking and chipping. Small diameter logs are debarked by friction in the dry state. Larger logs are wet friction debarked in a drum or pocket barker but is decreasing in importance to hydraulic barking which is largely practiced in the northwest. Hydraulic barking is more energy intensive than friction barking. Barking energy requirements shown in the four flowsheets are representative of friction barked roundwood.

About 12 - 15% of the weight of the roundwood processed is removed by barking (12.5% is used throughout this report) and only 85% of the

bark removed is combustible, the balance being imbedded sand, grit and dirt. This bark, with a gross heating value of 10.5 MM Btu/ton of wet bark (52% water), is burned in combination boilers along with chip fines to produce steam and electric energy for the mill.

Although mechanical pulping uses pulpwood as either roundwood or chips, chemical pulping exclusively uses chips. Fines produced during chipping, estimated as 2% of the debarked round wood input, are collected by screens and burned. Chip fines are assumed to have the same gross heating value as bark.

If a mill has available all its pulpwood available as chips, or if recycled paper is used for pulping, then there are no energy requirements for preparing fiber for pulping, but there are also no wastes available for electricity and steam generation.

Pulping. There are some 16 different pulping processes used in the U.S. although three chemical pulps (Kraft, semichemical and sulfite) and one mechanical pulping process (ground wood) account for in excess of 90% of all pulp production.

The major purpose of pulping is to remove the intercellular material, lignin, which holds together the major desirable material, cellulose. Chemical pulping uses chemical solutions at elevated temperatures and pressures to strongly attack and separate the lignin. Mechanical pulping relies on compression and friction and washing to partially remove the lignin. Yields are high in mechanical pulping because of the low degree of cellulose purification. Chemical pulping yields are usually low and depend to some extent on the quality of the fiber desired. Kraft pulping yields for newsprint, folding boxboard and topliner for corrugated containers are generally 45 - 47%. Kraft pulp yield for corrugated

container baseliner can be as high as 53%. Additional lignin removal occurs in the bleaching process with a subsequent reduction in fiber yield.

The fibers lost in chemical pulping and discharged with spent pulping liquors represents a valuable source of fuel. All Kraft mills, and semichemical pulping mills integrated with Kraft pulp mills, process the spent liquor for chemical recovery and simultaneously produce steam. The efficiency and economic viability of Kraft pulp mills strongly depends on the recovery of the fuel value of spent pulping liquors for the production of steam to be used in processing and for the cogeneration of electric energy used in the mill.

Bleaching. Although the principle purpose of bleaching is to decolorize and whiten pulp, the first stage of bleaching, using chlorine, serves to remove residual lignin not removed in pulping. Thus, the initial stage in bleaching is a continuation of the pulping process. Subsequent bleach stages mainly serve to whiten the pulp.

The extent to which pulp is bleached is expressed as a G.E. brightness, referring to a reflectance meter method of measuring the surface tone of the pulp. Bleached Kraft pulp must achieve a G.E. brightness of 75 while semibleached pulp must achieve a G.E. brightness of not less than 45 or more than 75. Kraft pulp is bleached according to its end use, a semi-bleach for newsprint to a heavy bleach for solid bleached boxboard. Kraft pulp made into linerboard for corrugated containers is not bleached, nor is the NSSC pulp used to make medium.

Groundwood is brightened either by peroxides, which oxidize color bodies present, or by hydro-sulfites (zinc or sodium) which chemically reduce color bodies. Kraft pulp is brightened by removing light absorbing substances such as lignins, resins, and non-cellulose materials.

Chlorine, chlorine dioxide and hypochlorites are used to delignify Kraft pulp, with caustic used to extract the chlorolignins formed. Bleaching of Kraft pulp is done in stages with alkaline extraction between each stage; the greater the brightness required, the greater the variety of bleach chemicals used. A three stage sequence such as CEHED (chlorination-alkaline extraction-hypochlorite bleach-alkaline extraction-chlorine dioxide bleach) is used to produce pulp intended for very bright papers.

Energy requirements for the bleaching of pulps depend on the type of pulp being bleached, the extent to which the pulp is bleached, and the wood source used for pulping. Northern woods, for example, produce inherently brighter pulp than wood from Southern regions. In some cases, such as in groundwood pulp manufacture, it is not necessary to bleach pulp made from Northern woods whereas a light bleach is mandatory for groundwood pulp made from Southern pulpwoods.

Paper and Paperboard Production. The manufacture of paper and paperboard products from pulp is accomplished by forming a matrix of fibers on a web or screen. The suspended fibers in the bleached or unbleached pulp are deposited on the web from stock chests where the pulp is prepared for forming by adding additional water to produce a consistency best suited to the machine used, beating the fibers, and adding sizing or other types of fillers. Water is removed from the formed sheet by pressing between rollers and then the sheet is further dried by heating. Paper and light weight boards are usually made on Fourdrinier machines; heavy paper and board and multi-layer sheets are most often made on Cylinder machines.

In addition to fillers and additives put into stock chests, other materials can be added to the formed paper or paperboard surfaces. These coatings can be added on the paper making machine or in a separate operation off the paper machine. Fillers and additives include materials such as clays, talc, and sizing agents. Surface coatings are often composed of pigments, adhesives and synthetic resins.

Electrical energy required to manufacture paper and paperboard is principally associated with drives for the paper machines, although some electrical energy is used for stock preparation (beating and refining) and pumping water. The electrical energy needed also depends upon the thickness of the sheet formed and whether or not coatings are applied on the paper machine.

Converting. The output from the paper/paperboard machine is raw paper in roll form. The processing of this bulk output into finished paper products is termed "converting" in the paper industry. For most consumer products, e.g. tissues, sanitary napkins, paper towels and sometimes bags, writing paper tablets, reams of typing paper, etc., converting operations are not generally performed at the paper mill but are instead located close to markets.

Energy requirements, mainly electrical, for converting operations are relatively low compared to other steps in the overall paper/paperboard manufacturing sequence.

2.0 NATIONAL DATA

Annual national capacity, production and energy usage data are presented in this section. Although the emphasis in the data compilations and analyses that follow is primarily aimed at the four paper and paperboard products selected to represent the pulp and paper industry, annual data for the entire industry are also presented.

2.1 Capacity and Production Data

The production of all grades of paper and paperboard products in the U.S. in 1976 totalled slightly less than 55 million tons compared with about 48 million tons in 1975[1]. Paperboard production accounted for slightly more than half the production of combined paper and paperboard in 1976 (23.4 million tons, 52%)[1]. U.S. paper and paperboard capacity in 1976 amounted to 68.3 million tons, giving rise to an average operating rate of about 80.5% for U.S. mills in that year[1].

Capacity and production data for 1975 and 1976, and estimates for 1977, are found in Exhibit 26-5 for each of the four paper and paperboard products selected for study. Regional data for 1976, capacity only, are presented in Exhibit 26-6. The data shown were developed from several different statistical sources and represent production and capacity figures as nearly as possible for the specific products previously described. In most cases, the defined products are part of a larger class or grouping of similar products or products made from different fiber sources. The notes to Exhibit 26-4 and 26-5 are for the purpose of putting in perspective production and capacity data for specific products compared with major product grades.

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1 "Statistics of Paper and Paperboard 1977", American Paper Institute, October, 1977.

In 1974, there were 412 companies operating 953 establishments throughout the United States although the leading fifty companies accounted for 54% of sales and the top ten companies 35% of total tonnage. There is a strong integration of paper and paperboard production with pulp mill operation as indicated by Exhibit 26-7 which offers justification for considering integrated production of the products selected for this study. Some idea of the number of machines and median machine capacity for these products is also shown.

2.2 Annual Energy Consumption

The pulp and paper industry, because of its size and the energy intensiveness of its manufacturing processes, is a large user of purchased fuels. In 1975, the industry was the fourth largest industrial user of total purchased fuels and electric energy of all the major industry groups and the single largest user of purchased fuel oil. In the consumption of purchased electric energy, the pulp and paper industry ranked third in 1975, but led the nation in self-generated electric energy, producing almost 37.5% of industrial electricity generation.

Some data on fuel usage by the industry and its major subdivisions are shown in Exhibit 26-8 for 1975 and 1971. These data show a general reduction of purchased fuels and electric energy in 1975 compared with 1971 although the reason is basically due to poor industry and national economic conditions rather than more efficient energy usage. More important, though, is the fact that despite a turndown in production

the total quantity of purchased and total electric energy consumed by the industry and its subdivisions increased. The smallest percentage increase in purchased electric energy is 9.5% for SIC 2611 pulp mills and the largest increase is 47.4% for SIC 264 converted paper products. The increased use of electricity is due to its generally smaller price increase compared with fossil fuels during this five year period, which spans the oil embargo of 1973, and the relatively greater availability of electricity than some of the fuel sources. It should also be noted that paper mills and paper and paperboard mills use a significantly smaller fraction of their purchased energy sources in the form of electricity than the converting industries, SIC 264 and 265. This is due to the fact that converters use a higher proportion of electricity to steam than do operations associated with pulping and paper and board forming and also that pulp mills and paper and board mills have internally generated wastes available (bark, chips, spent pulping liguors) which are used to generate onsite electric energy. This is further shown in the last two columns of Exhibit 26-8 where the percentage of electricity used which is self generated is shown. Pulp mills, paper and board mills generate rather large proportions of this electric energy requirements while converters do not. However, the trend for the five year period shown is toward less self-generation. It is believed that this trend will diminish, and may even reverse, as increased electricity costs catch up with fossil fuel prices and as the industry increases its use of wastes and residues.

Exhibit 26-9 presents the results of a regional analyses of fuels and electric energy usage. The data in this Exhibit can be interpreted

largely on the basis of the location of pulping and associated processes (paper and board production) in those regions of the country where large forests exist; South Atlantic, East South Central and Pacific (West). The greatest amounts of self-generated total energy and self-generated electricity are located in these regions. A major exception is self-generated electric energy in the Pacific region where the low cost of purchased electricity discourages onsite generation.

3.0 PROCESS AND PRODUCT ENERGY REQUIREMENTS

The section below examines steam and electricity requirements for major process steps in paper and paperboard manufacturing. Particular attention is paid to the existence of internally generated combustible wastes and the pulp and paper industry's practice in availing itself of wastes for energy production. The unit process energy requirements are then assembled to estimate energy requirements for four selected industry products.

3.1 Unit Energy Consumption Data

The consumption of energy as steam and electricity for specific process steps in paper and paperboard manufacture is shown in Exhibit 26-10 along with net total process energy requirements based on the recovery of steam in those processes producing combustible wastes. Steam and electricity are both required for pulping, bleaching, the production of paper and paperboard, and for converting.

3.2 Details of Steam and Electricity Consumption

For the processes shown in Exhibit 26-10 the ratio of steam to electricity requirements varies from 5 to 10:1 with the exception of groundwood bleaching. These ratios are quite feasible for inplant electric energy generation in extraction turbines which allow the withdrawal of steam at two or more pressure levels for process heaters. Most mills require steam at pressures of about 160 psig for pulping and lower pressure steam of about 60 psig for washing pulp, recovery furnace evaporator operation and paper and paperboard drying.

The most electric energy intensive process is for the production of groundwood where approximately 1700 kWh per ton of groundwood pulp is required. Barking and chipping of groundwood are much less electric energy intensive.

The recovery of energy in process wastes has significant potential for reducing process energy requirements. Bark and chip fines from wood preparation have gross fuel heating values of approximately 10.5 MM Btu per ton of wet bark or chips (16 MM Btu/dry ton assuming 52% wastes). On an equivalent energy basis, the wastes from barking and chipping are net producers of energy. Bark oil and chips are extensively used to fire steam boilers for the generation of process steam and the cogeneration of electric energy although these fuels are difficult to work with. As much water as possible must be expressed from these wastes before they can be used. In general, a mill with fiber source in the form of roundwood can produce almost 1.5 MM Btu in steam from the bark and chip wastes. This steam, in turn, can be used to generate more than the 41 kWh of electric energy required for barking and chipping as well as serve for process heating. Mills operating exclusively with wood chips or with recycled fibers avoid the energy required for wood preparation, but also have no wastes to generate steam and power for downstream processes.

Chemical pulping (Kraft and NSSC) also produce combustible wastes which can be used to generate steam and electricity. Here, however, the pulping liquors can be used only to reduce the high energy requirements of chemical pulping. Some 3.6 MM Btu from spent Kraft pulping liguors and about 2.2 MM Btu from spent NSSC pulping liguors can be generated.

Groundwood pulping, with its high yield (94-95%) produces no useable wastes which can be used to offset the high electric energy required.

Paper and paperboard making processes also produce wastes but these are generally not used for fuels. The wastes, called broke, result from trimming and cutting paper and board after forming and damaged goods. Broke is most often mechanically repulped and blended with the furnish to the paper and board machines. Paper and paperboard manufacturing that are not integrated with paper or paperboard mills most often raise steam for repulping purchased dry pulp and for drying with onsite boilers but purchase all their electricity needs as do converting plants.

The extent to which segments of the pulp and paper industry cogenerate steam and electric energy was previously displayed in Exhibit 26-8. It was shown there that a significant portion of required electric energy is presently produced by the portions of the industry where significant amounts of combustible wastes are available.

3.3 Energy Consumption for Selected Paper and Paperboard Products

The data of Exhibit 26-10 were used to assemble the specific energy requirements for each process step shown in Exhibits 26-1 through 26-4, for the production of four selected paper and paperbaord products. A plant-wide summary of energy requirements for each selected product is shown in Exhibits 26-11 through 26-14 analyzed in Exhibits 26-15 and 26-16. Each plant summary shows the source and quantity of fuels used to produce one ton of each product. Because each product is produced in mills integrated with pulping facilities, it was assumed that electric energy was cogenerated to the greatest extent possible from all fuels. Boiler efficiency for steam generation with fossil fuels was assumed to be 80%, and 70% and 60% respectively for bark and chips and spent pulping

liquors. The efficiency for electricity cogeneration was assumed to be 30 kWh/million Btu in boiler steam. The distribution of purchased fossil fuels for each mill was based on industrial fossil fuel usage for specific regions of the country.

The analysis of these paper and paperboard production systems in Exhibit 26-15 and 26-16 shows that, with the exception of newsprint, writing paper, corrugated containers and folding boxboard require very little purchased electricity although they each require more total energy per ton of finished product than does newsprint. However, the balanced demand between steam and electricity is such that purchased fossil fuels plus internally available process wastes are sufficient to generate onsite almost all the electric energy needed. Writing paper, linerboard and medium for corrugated containers and SBS folding boxboard production systems each produce more than 50% of electricity demand. This is not true for newsprint production largely because of the high electric energy intensiveness of groundwood pulping and the lack of combustible wastes from this pulping process. It should be understood, though, that the exact amount of required energy for these four processes are specific for the products as defined and the mix of chips and roundwood assumed for each. Individual mills producing similar products will have more or less total energy consumption and purchased electricity requirements because of process variations, type of pulpwood mix available, and even the age of the mill.

Based upon the energy analyses of the four hypothetical plants, annual and unit energy requirements for the industry's entire 1975 production of these selected products may be estimated. These are shown in Exhibits 26-15 and 26-16.

4.0 ANTICIPATED TRENDS

Industry growth to the year 2000 is discussed here along with those factors, such as environmental control and energy sources, which are stimulating the development of new process technology.

4.1 Product Growth Trends

Total paper and paperboard product growth to the year 2000 were estimated in several ways with results shown in Exhibit 26-17. A linear extrapolation of historical growth of total paper/paperboard capacity predicts about 112 million ton capacity by the year 2000. This corresponds to an annual compound growth rate of about 2.1%. American Paper Institute projected growth over the shorter period 1976 - 1982 is at a slower annual rate, about 1.9%. This growth rate is considerably less than the industry's growth rate in the recent past, estimated as an average of 4.0% for the 14 year period 1956 - 1969 and 2.4% for the 8 year period 1970 - 1977. To a considerable extent, the reduced industry growth rate is linked to the recent recession, which severely affected the industry, and uncertainty with respect to national economic growth. In specific product areas, such factors as competition from alternative products, plastics for packaging, for example, and the capacity plans and cost of Canadian newsprint, impact on the industry's growth. Certainly, estimates of future growth based on per capita consumption of paper and paperboard products and growth related to the national GNP appear overly optimistic. The linear growth prediction would appear to represent a reasonable maximum for this industry over the long term.

For three of the products (newsprint, corrugated containers and folding boxboard) capacity figures are shown below. Production rates can vary from as low as 80% in low demand years to 98-99% in good years. A factor in this range, depending on estimates of the national economy, should be applied to the capacity data in order to estimate annual production. Note, however, that for writing paper the figures in the table are production estimates as discussed in the table footnotes:

Estimated Capacities* of Selected Paper and Paperboard Products in 1985 and 2000
(all data in thousand tons)

Product	1975	1985	2000
Newsprint[a]	3848	4900	7100
Writing Paper[b]	3244	4000	5400
Corrugated Containers[c]	17,674	20,500	28,000
Folding Boxboard[d]	3610	5400	8400

* production estimates in case of writing paper (see note b below)

(a) Committed capacity increases amount to 300,000 tons of newsprint between 1978 through 1982 and additional 130,000 tons under consideration. If all this increased capacity is realized, the compound annual growth rate for the period is about 2.0% which is at a lower growth rate than the 2.9% recorded by the industry for the period 1970-1977. The 1985 estimated newsprint capacity of 4,900 in tons is based on the assumption of a 2.0% growth rate from 1977 through 1985. The estimated newsprint capacity in the year 2,000 is based on a slightly larger growth rate, 2.5%, between 1985 and 2000.

(b) Note that the figures given in the table to the year 2000 are writing paper production, not capacity. As noted in the report, capacity data are not available because of definition and classification difficulties in this paper category. Writing paper production estimated for 1985 and 2000 were arrived at by assuming that growth would be identical to capacity growth rate for the entire writing and related paper category which is estimated as 2.2% annually between 1977 and 1985 and 2.0% annually between 1985 and 2000.

(c) Unbleached Kraft paperboard capacity is expected to increase by about 1,200 m tons between 1978 and 1982. However, unbleached Kraft liner board capacity for corrugated containers is expected to slightly decrease partly due to poor export demand. Semi chemical medium for corrugated containers experienced a rather large capacity growth between 1970-1976 and little demand for increased capacity is anticipated. We estimate only a nominal capacity increase to 20,500 m tons of total corrugated containers by 1985 and a continued small demand increase to 2,000. The year 2,000 capacity is based on a 2% compound capacity growth between 1985 and 2000.

(d) Solid bleached paperboard capacity is expected to experience a strong growth through 1982 and will most likely continue through 1985 at about 4% per year. Capacity increase thereafter is assumed to decrease to about 5% per year through the year 2000.

4.2 Process Changes

Discussed below are some new process technologies in three major areas of pulp and paper/paperboard manufacturing. New process techniques in pulping will have an impact on pulp mills producing market pulp and on integrated paper and paperboard mills. Potential new processes in forming and drying paper will have an effect on the larger number of paper and paperboard manufacturers using market pulp as well as on integrated paper and paperboard mills.

Pulping

A large number of new pulping techniques are being examined by the industry, many of them conceived for the purpose of reducing air emissions and wastewater effluents associated with conventional pulping using sulfur compounds. Among new pulping processes receiving much attention are alkaline-oxygen pulping, Rapson effluent-free Kraft pulping, solvent pulping (using organic alcohol-hydrochloric acid mixtures, or amines), biological pulping and ammonia explosion pulping and several more. Many of these new techniques are still experimental or have serious shortcomings that must be overcome before they can be seriously considered.

For most of these new processes, there are no reliable data on differences in energy consumption with Kraft pulping. Estimates of energy requirements for the alkaline-oxygen and Rapson pulping processes compared with conventional Kraft pulping, from a recent EPA study[1], are shown in the table below.

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1 Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Vol. V "Pulp and Paper Industry Report", EPA-600/7-76-034e, December 1976.

Process	Total Energy (10^6 Btu/ton)	Electric Energy (% of Total)	Recovered Energy (10^6 Btu/ton)	Net Purchased Energy (10^6 Btu/ton)
Standard Bleached Kraft	25.4	13.8	18.0	7.4
Alkaline-Oxygen	20.4	11.3	16.1	4.3
Rapson	20.1	12.9	18.0	2.1

In addition to a reduction of about 20% for total energy requirements, purchased energy appears to be sharply affected as well as significant reductions in electricity used. The alkaline-oxygen and Rapson pulping processes are also reported to be slightly less, 5-10%, capital intensive for new large mills. The combined advantages of reduced energy consumption and capital requirements and better pollution characteristics could prove attractive to the industry in the future.

The impact of increased secondary fibers should be mentioned here. In general, the use of recycled fibers requires less total energy than the manufacture of the same product using pulp produced from virgin wood. However, there is a loss of combustible mill residues with secondary fiber processing which raises the quantity of purchased energy, including electricity, required per ton of product. The API estimates about a 26% increase in the use of recycled paper and board for all products from 1976 to 1980.

Bleaching

Most pulp, currently, is bleached with chlorine in several stages, with alkaline extraction (or washing) of the bleach solution between stages. Both oxygen and chlorine dioxide are being considered as replacements for chlorine in bleaching operations. Most of the

new bleaching processes are being examined for the purpose of reducing water emission problems associated with the large amount of water required for inter-stage washing. The impact on electricity requirements of these new processes would have to be carefully examined. Considerable energy savings could be realized, in terms of energy required for chemical bleach production and in-plant energy used in bleaching and washing stages, if pulps were bleached to a generally lower extent than is now practiced. To some very small extent, this is being practiced visibly now by some newspapers and inexpensive quality magazines. However, consumer demand for bright paper products is expected to remain high, if not increase, and little reduction in energy consumed for bleaching is expected.

Papermaking

Most paper, as currently made, requires that a dilute solution of refined fibers (stock) flow over a wire mesh and, as the wire travels forward, water drains by gravity and then by suction to form the sheet. Additional water is removed by pressing and finally by passing the formed sheet over steam heated drums. Fourdrinier paper machines operate up to speeds of 5000 feet per minute for tissue forming (for machine widths of 100 to 380 inches), 3000 fpm for newsprint and 2500 fpm for fine papers. Drying is usually accomplished with low pressure steam heated rolls, although some paperboard is dried with high pressure steam and some paper and board are dried by direct firing with natural gas.

There are some specific limitations associated with Fourdrinier paper forming, specifically the speed of forming which is limited to

the rate at which water first drains from the formed sheet. Research into faster operating machines is an ongoing industry effort and includes methods for forming the sheet from higher consistency stocks and better, less costly methods, of drying. New developments in these areas include (a) twin-wire forming of paper which allows water drainage from both sides of the formed sheet, (b) high consistency headboxes developed in Sweden and Finland and being tested in the U.S., (c) improved drying methods such as microwave and dielectric drying, radiant drying (electrical and gas fired), flow-through air drying and fluidized bed drying (particularly for pulp) and, rather remote at present, waterless paper forming (dry forming). Almost all of these methods hold promise of increased productivity at lower cost and reduced energy consumption, particularly for drying. If the thermal energy for drying is reduced, or if drying relies less heavily on steam, than a greater fraction of purchased electric energy will be required for papermaking in the future. How much more will depend on each new innovative method being considered. These changes will have a particularly important impact on the pattern of electricity use in integrated mills, but particularly in mills making paper from purchased pulp.

4.3 Implementation of New Technology

Although the pulp and paper industry is intensely examining new process technology, a number of important factors will determine how rapidly new technology will be accepted by the industry. Chief among these factors is the financial condition of the industry. After two

good production years in 1972 and 1973, demand for pulp and paper industry products fell off badly in 1975 to the point where operating rates were about 79% of capacity. Although recovery has been rapid (operating rate of 88% in 1976), the industry is making cautious plans for new capacity. The American Paper Institute estimates additional capacity at 1.8% of industry total in 1977 and at about 2.5% for 1978 and 1979. Most expansions appear to be capacity roundout rather than new plants. This kind of conservative approach usually embraces existing rather than new technology.

The pulp and paper industry is also concerned with environmental and fossil fuel energy resource problems that tend to dominate its near term decisions. Air and water emission problems are competing with capital requirements for new projects and the industry is concerned with replacing its high reliance on fuel oil as an energy source with other forms of energy.

It would appear that the industry will most likely embrace small process improvements in the near future that tend to relieve immediate problems with rather well known technology changes that will not alter its energy picture appreciably. In the long term, significant changes will come about but only for greenfield additions. The industry is too capital investment intensive to rapidly abandon operating plants and equipment.

4.4 Trends in Energy Requirements

Studies were performed in 1976 - 1977, for the then Federal Energy Administration (FEA), for the purpose of setting attainable

reduction targets, by 1980, of industry energy consumption relative to 1972 energy usage. The FEA target for SIC 26, Paper and Allied Products Industry was a 12% net reduction of total energy consumed and a 28% net reduction of fossil fuels and purchased energy[1]. These net reduction targets included offsets to gross targets due to energy expended for governmental programs such as pollution control.

The support target document[2] notes several important energy characteristics of the industry:

- SIC 26 was divided into two sectors; Sector I comprising pulpmills, paper and paperboard mills, and building paper and board mills, consumes 91% of all energy used in SIC 26. Sector II, consisting of paper and paperboard converters which consumes only 9%.
- The pulp and paper industry is rather sensitive to operating ratio. Fossil fuels and purchased energy consumed per ton of mixed products increases by about 8.5% as capacity utilization decreases from 95% to 80%.
- Because of the large quantities of air and water used in process operations, energy consumption is rather sensitive to annual variations in climatic conditions and to differences in regional climates.
- Measures of energy consumption efficiency are dependent upon fuel mix. This is particularly true upon comparing the efficiency of fossil fuels for energy production compared with low efficiency waste fuels (bark, chips, spent pulping liquors).

These combined factors make predictions of future energy requirements somewhat difficult. The API, reporting for the entire industry, indicated that in 1976 all companies used 5.3% less purchased fossil fuels and energy compared with 1972 and, when adjusted by the above factors, the improvement was 9.3%. We estimate that a 12% reduction in unit energy consumption for the entire industry by 1985 is likely, with a reduction of about 16% (relative to 1975) by 2000. These reductions will probably be distributed uniformly across all available energy sources.

With respect to the breakdown of fuels used, four general trends in the industry should be noted:

- A reduction in coal usage to avoid the environmental effects of particulate and sulfur emissions encountered in combustion processes.
- Increased use of purchased electric energy in place of fossil fuels due to the more rapid increase in prices of fossil fuels This has also led to decreased self-generation of electricity.
- Increased use of internally generated wastes and forest residues as an energy conservation strategy.
- An effort to decrease natural gas usage in favor of residual and distillate fuel oil. Also, increased storage of fuel oils to minimize the effects of an embargo or local supply interruption.

The distribution of energy used among fuel types for the four products may be derived from Exhibits 26-11 through 26-14 for the year 1975. This, along with estimates for 1985 and 2000 are reported below:

Percent Distribution of Fuel by Product

	Newsprint			Writing Paper			Corr. Containers			Folding Boxboard		
Fuel	1975	1985	2000	1975	1985	2000	1975	1985	2000	1975	1985	2000
Internal Wastes	35	36	36	47	48	48	46	47	47	53	54	54
Purchased Fuel Oil	14	15	14	20	21	19	16	17	16	14	15	14
Purchased Gas	16	15	14	15	13	13	26	25	24	23	21	20
Purchased Coal	8	6	7	13	12	14	12	10	[illegible]	9	8	9
Purchased Electricity	27	28	29	5	6	6	0	1	2	1	2	3

5.0 PLANT-SPECIFIC DATA

Additional data describing specific plant energy requirements are included in this section along with indications of load profiles, state conditions and reliability considerations. Several plant factors are summarized in Exhibit 26-18. The information provided here, some of which is indicated as specific to each product considered also contains general comments which apply equally to all four different products.

5.1 Load Profiles

The integrated manufacture of pulp and paper and paperboard is inherently a semicontinuous operation. The basic form of materials passing through the production sequence changes from solid (roundwood and chips) to semifluid (pulp slurry) and finally back into a solid (forming paper and paperboard). It is therefore not possible to consider the sequence as truly continuous as would be the case for processing fluids, for example. Each process step will generally be operated continuously using feed materials which have been produced and stored in an upstream process. Chemical pulping, for example, will work off stockpiles of chipped roundwood, and paper and paperboard will work off storage tanks of pulp. Any breakdown in process equipment of short duration, therefore, will not seriously affect a downstream process. All the individual steps are continuous with the exception of older mills which produce pulp in batch digesters. Newer mills invariably employ continuous digesters which requires less thermal energy than batch pulping. But these, too, will work on stored wood ready for pulping.

Because of the continuous nature of each step in the overall process sequence, and the simultaneous demand for steam and electric

energy in nearly all production phases, the coincident demand for steam and electricity is high. Exhibit 26-18 indicates an electrical load factor of greater than 0.9 and a thermal-electrical coincidence factor of 1.0. Any electrical interruption in processing usually means a waste of steam. For example, a paper break on paper forming machines will put drivers in idle but there will be no demand for steam to dry the paper. In that case, steam is usually blown off. In some cases, for steam turbines of appropriate design, steam extraction can be switched to full condensation with resulting greater electricity generation.

5.2 Energy Flow Schematics

The use of electricity and steam for individual process steps have been previously discussed and are shown for four different product sequences in Exhibits 26-1 through 26-4.

In addition, Exhibits 26-19 through 26-22 show steam balances and electricity cogeneration for two different mill configurations. Exhibits 26-19 through 26-21, when combined, depict steam plants for Kraft topliner (26-19), Kraft bottom liner (26-20) and NSSC pulping with cross-recovery of pulping wastes with Kraft pulp (26-21). Exhibit 26-22 shows a steam plant for a bleachable grade of pulp.

Exhibits 26-23 and 26-24 present information on boiler installations in the pulp and paper industry in the U.S. No identification of electricity cogeneration capacity is available nor an identification of steam boilers with specific segments of the industry.

5.3 State Conditions and Mass Flows

Typical steam pressures and quantities used are shown in Exhibits 26-19 through 26-22. Generally, process steam at two pressures is used. High pressure steam is most often exclusively used for digesters and low pressure steam for the balance of mill requirements. The four mill processes shown use the following quantities of high and low pressure steam and electricity per ton of product:

Mill & Product	High Pressure Steam PSIG	High Pressure Steam lbs.	Low Pressure Steam PSIG	Low Pressure Steam lbs.	Electricity kWh
Kraft, topliner	150	3,300	70	10,340	700
Kraft, baseliner	150	3,300	70	11,310	700
NSSC, medium	150	2,200	70	16,300	1,170
Kraft, bleached	150	8,150	50	3,800	800

5.4 Reliability Considerations

As indicated previously, the integrated operations of pulping and paper and paperboard making is a semi-continuous process, each stage in the operation working off materials produced and stored in prior steps. To the extent that there is storage capacity, each sequence of the overall process can suffer a power loss with no simultaneous impact on other process steps. For example, power failure to the wood preparation stage is not immediately felt by the next stage, pulping. However, as stored chips are used up, pulping will be discontinued until more chips are provided, the impact depending on the extent to which chips from storage are available. There could also be difficulty in machine jams caused by roundwood being caught in barkers and chippers experiencing a power failure. Removing wood from equipment and restarting the process can be costly and time consuming.

Power failure in the pulping stage, of any significant duration, will result in a loss of the contents of a batch or continuous digesters. In batch digesters, the rate of temperature increase of cooking liguor, and the time held at elevated cooking temperatures, are carefully timed procedures and depends on the type of wood being pulped and the type of pulp being produced. In continuous digesters, these timed cooking practices are controlled by the rate at which wood enters the digester and passes through. Serious departures from the timing can result in poor quality pulp which must be discarded. The use of the expression "serious departure" is intended to be vague because pulping times can be as short as 15-20 minutes to as long as 120 to 150 minutes.

The final steps in paper and boardmaking, forming and drying operations, are particularly sensitive to power failures and even to voltage variations. Breaks in the paper sheet or board being formed occur if motor speeds driving the paper machines vary, the extent of the variation being dependent on the forming speed and the strength of the sheet. For example, in one case, a variation of one foot per minute would cause a newsprint paper break on a Fourdrinier machine operating at 2500 fpm. Normal operation usually includes three to four breaks a shift, each break taking from five to ten minutes to correct. To a lesser extent, the same inconvenience occurs in paperboard production because of the greater thickness and strength of this type of product.

EXHIBIT 26-1

PROCESS FLOW SHEET - NEWSPRINT

MATERIALS AND ENERGY CONSUMPTION DETAIL FOR 1 TON OF NEWSPRINT PRODUCED IN AN INTEGRATED MILL IN THE U.S. IN 1971.

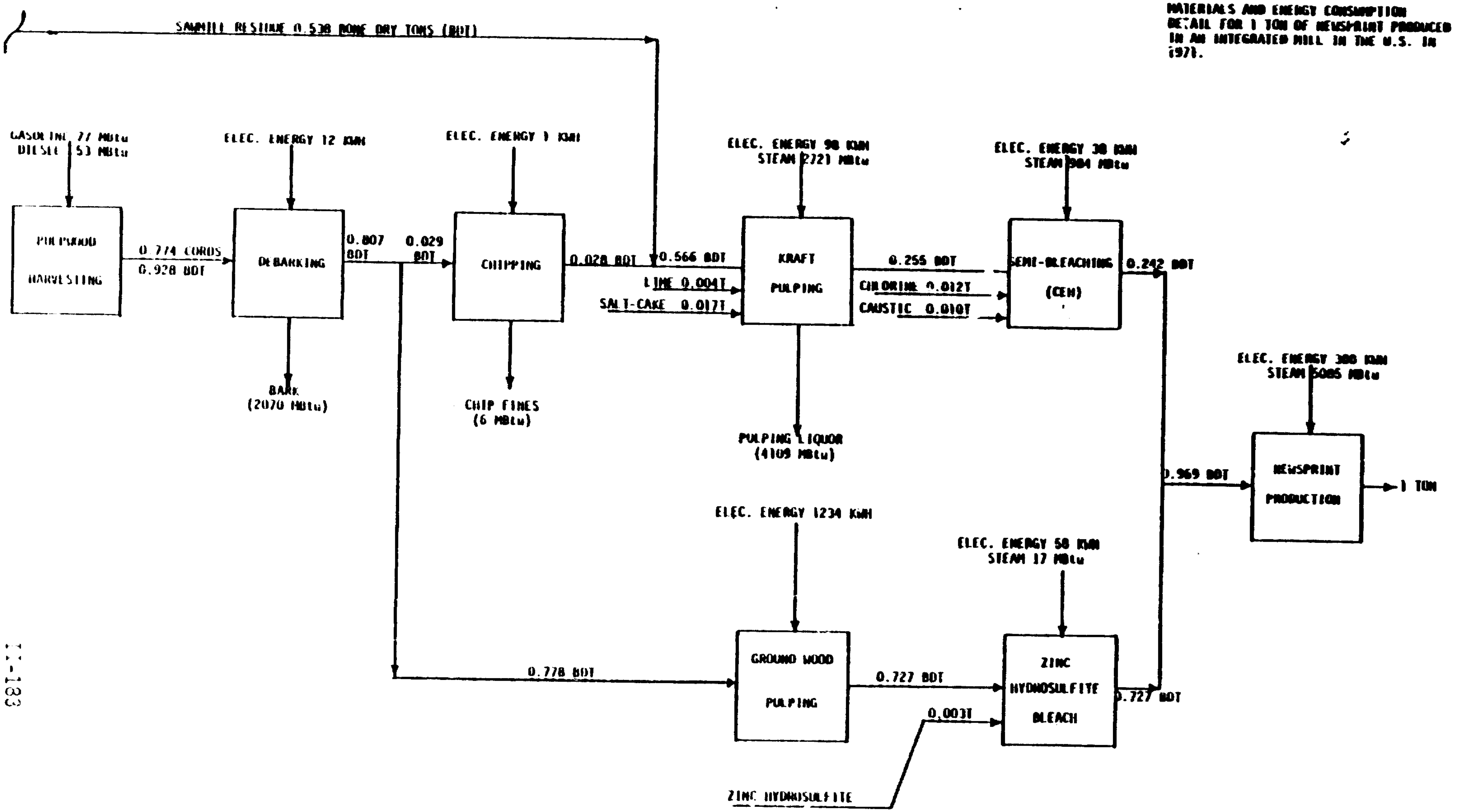


EXHIBIT 26-2

PROCESS FLOW SHEET - WRITING PAPER

MATERIALS AND ENERGY CONSUMPTION DETAIL FOR 1 TON OF CONVERTED WRITING PAPER PRODUCED FOR AN INTEGRATED MILL IN THE U.S. IN 1971.

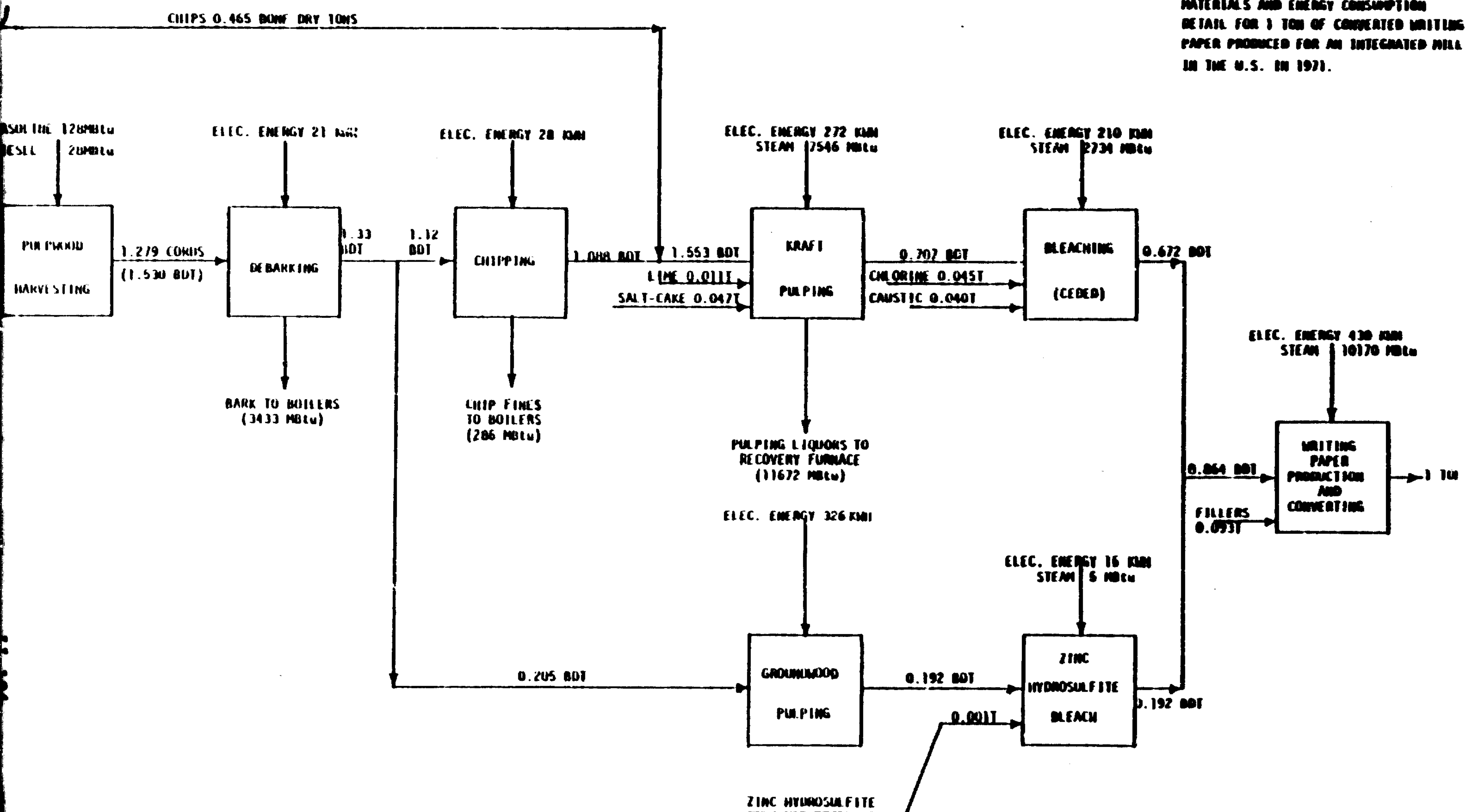
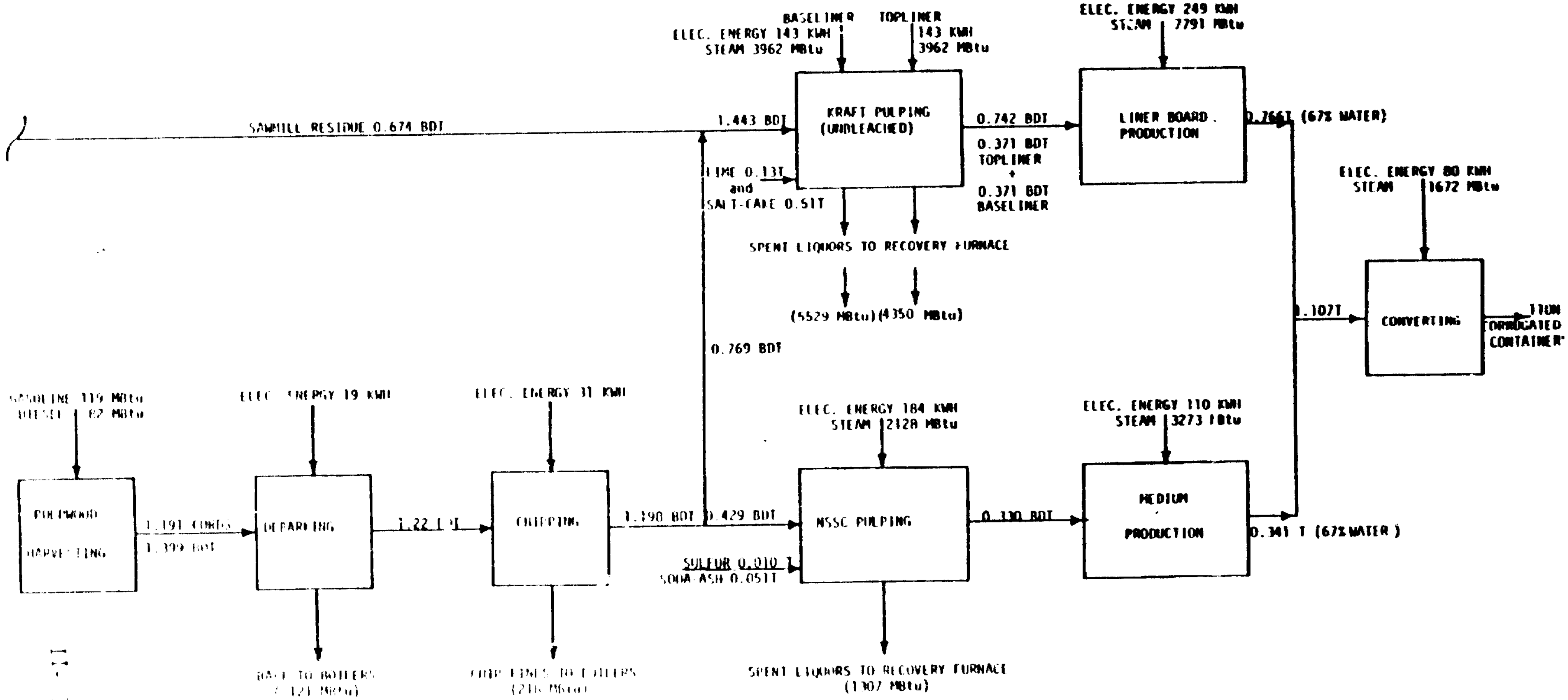


EXHIBIT 26-3

PROCESS FLOW SHEET - CORRUGATED CONTAINERS
MATERIALS AND ENERGY CONSUMPTION DETAIL FOR
1 TON OF CONVERTED CORRUGATED CONTAINER IN
AN INTEGRATED MILL (OFF-SITE CONVERTING)
IN THE U.S. IN 1971



C-3

PROCESS FLOW SHEET - FOLDING BOXBOARD
MATERIALS AND ENERGY CONSUMPTION DETAIL FOR 1 TON OF FOLDING BOXBOARD PRODUCED IN AN INTEGRATED MILL IN THE U.S. IN 1971

EXHIBIT 26-4

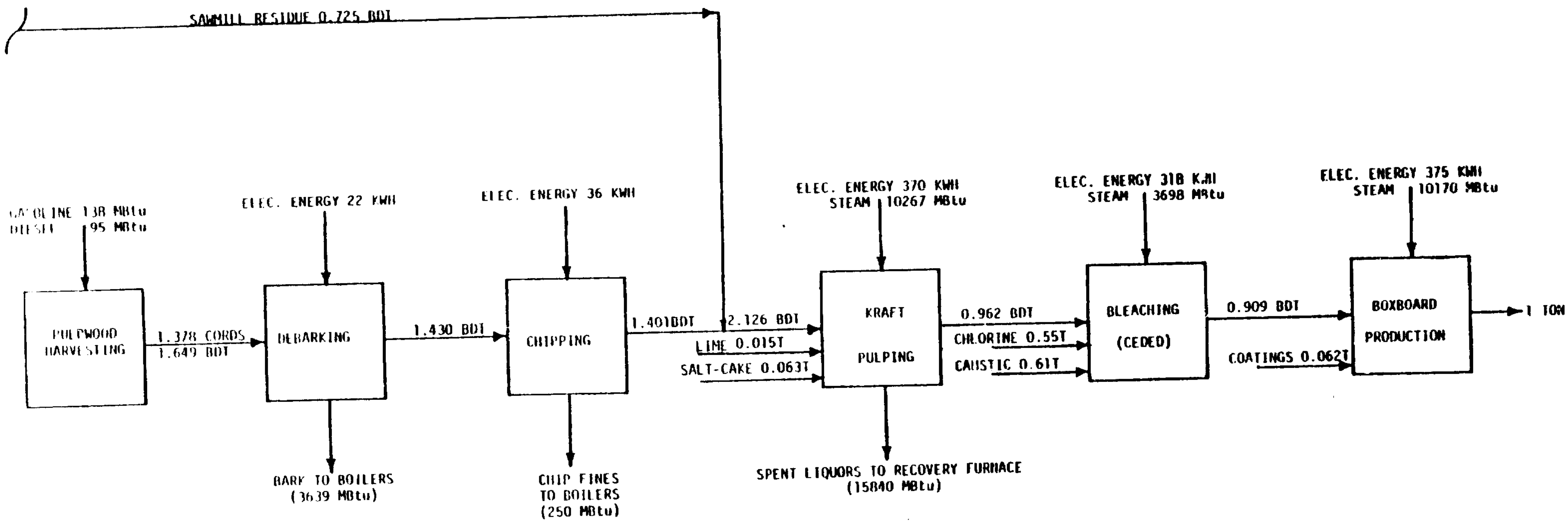


EXHIBIT 26-5

PRODUCTION, CAPACITY AND OPERATING RATE DATA FOR SELECTED PAPER AND PAPERBOARD PRODUCTS 1975-1977

	1975	1976	1977e
Newsprint[1]			
Production (M tons)	3,476	3,526	3,818
Capacity (M tons)	3,848	3,973	4,150
Operating Rate (%)	90.3	88.8	92.0
Writing Paper[2]			
Production (M tons)	3,244	3,721	NA
Capacity (M tons)	NA	NA	NA
Operating Rate (%)	NA	NA	NA
Corrugated Containers[3]			
Production (M tons)	14,846	16,283	18,448
Capacity (M tons)	17,674	18,271	18,936
Operating Rate (%)	84.0	89.1	97.4
SBS Folding Boxboard[4]			
Production (M tons)	2,918	3,316	NA
Capacity (M tons)	3,610	3,694	3,796
Operating Rate (%)	80.8	89.8	NA

e - estimated
NA - not available

Source: Production and capacity data for 1975 and 1976, and estimated capacity data for 1977 are from "Statistics of Paper and Paperboard 1977", American Paper Institute, October 1977. Estimated production data for 1977 are from Pulp & Paper, 51 (No. 7), (June 30) 1977 which contains a mid-1977 status report on the pulp and paper industry.

Notes to Exhibit 26-5

(1) Newsprint consumption in the U.S. was 9,159 M tons in 1975 and 9,969 M tons in 1976, only a part of which is produced in this country. Imports of newsprint, almost exclusively from Canada, make up the difference, 5,847 M tons in 1975 and 6,569 M tons in 1976, or approximately 63-65% of U.S. consumption. Newsprint production in the U.S. is about 13-15% of all paper grades manufactured. About 14% of U.S. newsprint production is from recycled waste news or about 5% of U.S. newsprint consumption.

(2) Production data for writing paper, as defined in this study, are reported by the API under the general category, "Writing and Related Papers". Writing chemical wood pulp constitutes the largest group (83%) within this category with the remainder comprising thin papers (910%), cover and text papers (5%), and cotton fiber paper and index (3%). Capacity data are not reported on the same basis as production data and therefore are not listed in the table. The closest approximation to writing and related papers capacity can be found in Table XXII, p.21 of the API "Statistics of Paper and Paperboard 1977" as the total of uncoated free sheet, cotton fibers, and thin paper which in 1975 and 1976, respectively, were 7,686 M tons and 7,836 M tons.

(3) Corrugated container production and capacity data are not directly reported by the API. Instead, production data for linerboard and corrugating material used for domestic containerboard and U.S. Census data which includes export data for linerboard and corrugating material were combined as follows:

	1975	1976
Linerboard (tons)		
Unbleached Kraft	10,884,699	12,266,815
Solid Bleached	81,800	99,500
Recycled	207,300	282,700
Total	11,173,799	12,649,015
Export (Unbleached Kraft)	1,224,211	1,419,361
Net Domestic	9,949,588	11,229,654

	1975	1976
Corrugating material (tons)		
Unbleached Kraft	8,700	20,200
Semi-chemical	3,960,942	4,016,217
Recycled	870,000	1,075,100
Total	4,839,642	5,111,517
Export (semi-chemical)	36,796	55,275
Net Domestic	4,802,846	5,056,242

Total corrugated container production, defined in this study as consisting of unbleached Kraft linerboard and semi-chemical corrugating medium, can be estimated from the data above for 1975 and 1976. These total to 14,846 M tons in 1975 and 16,283 M tons in 1976. Based on net domestic use, the ratio of linerboard to corrugating medium was 2.07 in 1975 and 2.22 in 1976. These ratios, as well as the estimated corrugated container production are too high because some corrugated medium is used as wrapping rather than in corrugated containers. The quantities of corrugated containers shown for 1975 and 1976 account for about 58-61% of all paperboard produced in the U.S.

(4) Folding boxboard production and capacity data includes solid bleached sulfate (SBS) paperboard for milk carton and food service containers as well as for folding boxboard. Milk carton and food service boxboard is almost exclusively solid bleached. Solid bleached folding boxboard constitutes about 37-38% of all folding boxboard

EXHIBIT 26-6

1976 REGIONAL CAPACITY FOR SELECTED PAPER AND PAPERBOARD PRODUCTS[a]

Census Region	Newsprint (M tons)	Newsprint (%)	Printing, Writing and Related Papers[b] (M tons)	Printing, Writing and Related Papers[b] (%)	Corrugated Containers[c] (M tons)	Corrugated Containers[c] (%)	Folding Boxboard[d] (M tons)	Folding Boxboard[d] (%)
New England	412	10.2	2,646	19.6	176	1.0	29	0.7
Mid-Atlantic	214	5.3	2,053	15.2	--	--	--	---
East North Central	127	3.2	3,681	27.3	1,203	6.5	3	0.1
West North Central	---	--	779	5.8	173	1.0	--	--
South Atlantic	373	9.3	1,433	10.6	7,615	41.7	1,648	40.6
East South Central	963	23.9	965	7.2	2,958	16.2	714	17.6
West South Central	914	22.6	939	6.9	3,092	16.9	1,116	27.5
Mountain and Pacific	1,029	25.5	1,001	7.4	3,052	16.7	547	13.5
Total	4,032	100.0	13,497	100.0	18,269	100.0	4,057	100.0

Source: "1976-1979 Capacity, Paper, Paperboard, Woodpulp", American Paper Institute, 1977

a Total capacity for each product category shown may not exactly agree with capacity data shown for 1976 in Exhibit 26-2 because source of data are different and for reasons cited individually below.

b Capacity data for writing paper above is not specifically given by the API source cited above. The printing, writing and related category contains writing paper and is the only data available. It does not follow that writing paper is distributed by census region as the capacity of the larger category.

c Capacity shown is the sum, for each census region, of unbleached Kraft linerboard and semi-chemical paperboard which together make up the corrugated container product category. The capacities shown are therefore not necessarily finished corrugated containers but only the total of linerboard and medium produced in each region. For example, capacities shown for the New England, East and West North Central regions are for semi-chemical paperboard only, not corrugated containers. There is virtually no unbleached linerboard produced in these three regions.

d Capacity data for the folding boxboard category were estimated from capacity reported for solid bleached paperboard in the API source cited above. Some of the difference in total of Exhibits P-5 and P-6 is due to the fact that some bleached paperboard is used for linerboard and other categories.

EXHIBIT 26-7

INDUSTRY STRUCTURE FOR THE PRODUCTION OF SELECTED PAPER AND PAPERBOARD PRODUCTS

Paper/Paperboard Grade[a]	% Annual Capacity Integated to Wood-pulp (1976)	Total Number of Machines[b,c]	Median Machine Capacity (M tons/yr)
Paper			
Newsprint	89	38	101-125
Uncoated Free Sheet	65	278	21-30
All Paper	73	981	--
Paperboard			
Unbleached Kraft	100	69	151-200
Semi-chemical	100	51	76-100
Solid Bleached	100	31	126-150
All Paperboard	74	395	--
Total Paper and Paperboard	74	1,376	--

Source: "Paper, Paperboard, Woodpulp 1976-1979 Capacity", American Paper Institute, New York, 1977.

a Does not include construction paper and paperboard

b Because a mill may have more than one operating machine, the total machines in each category do not correspond to the total number of mills

c Machine identification is based on principal grade of paper or paperboard products; many machines produce different grades of products on an annual basis.

EXHIBIT 26-8

PURCHASED FUELS, ELECTRICITY AND SELF-GENERATION IN THE PULP AND PAPER INDUSTRY, 1971 AND 1975

		Total Purchased Fuels and Electric Energy (10^9 kWh Equivalent)		% Total Purchased Fuels Which is Electric Energy		Total Electric Energy Consumed (10^6 kWh)		% Total Electric Energy Consumed Which is Self-Generate	
SIC No.		1975	1976	1971	1975	1971	1975	1971	1975
26	Paper and Allied Products	385.4	354.6	9.1	11.1	60,367.6	63,553.0	42.2	38.4
2611	Pulp Mills	26.2	24.1	9.5	10.4	4,814.6	4,732.9	48.1	46.2
2621	Paper Mills	171.3	155.6	9.9	11.3	29,471.3	29,334.4	42.5	40.0
2631	Paperboard Mills	134.7	133.7	5.0	7.2	17,124.7	19,889.6	60.6	51.8
264	Converted Paper Products	20.3	16.8	19.4	28.6	NA	4,935.4	NA	1.6
265	Paperboard Containers and Boxes	19.5	14.3	16.3	22.4	NA	NA	NA	NA

Source: Derived from "Annual Survey of Manufactures 1975, Fuels and Electric Energy Consumed", Bureau of the Census, U.S. Department of Commerce, September 1977.

EXHIBIT 26-9

PURCHASED ENERGY, ELECTRICITY AND SELF-GENERATION ON A REGIONAL BASIS FOR THE PULP AND PAPER INDUSTRY, 1975

Region	Purhcased and Self-Generating Energy Consumed (10^{12} Btu)	Energy Consumed which is Self-Generated (%)	Total Electric Energy Consumed (10^9 kWh)	Total Energy Consumed Which is Electric Energy (%)	Electric Energy Consumed Which is Self-Generated (%)
New England	122.0	27.1	5.9	14.2	45.8
Middle Atlantic	89.0	16.9	3.9	13.0	35.9
East North Central	199.0	14.6	7.9	11.9	49.4
West North Central	34.5	21.7	1.5	12.9	35.3
South Atlantic	580.0	51.7	14.0	7.6	71.4
East South Central	280.0	53.6	7.2	8.1	59.7
West South Central	290.0	48.3	8.6	9.2	58.1
West	290.0	55.2	10.0	10.5	14.0
Total U.S.	1,890.0	44.4	59.0	9.6	49.2

Source: Data developed from, "A Study of Inplant Electric Power Generation in the Chemical, Petroleum Refining and Paper and Pulp Industries", Thermoelectron Corporation.

EXHIBIT 26-10

ENERGY CONSUMPTION AND ENERGY RECOVERY POTENTIAL FOR SELECTED PROCESS STEPS IN PAPER/PAPERBOARD MANUFACTURE

(per bone dry ton of process step output)

Process	Electric Energy (kWh/BD ton)[a]	Steam (MBtu/BD ton) 160psig	Steam (MBtu/BD ton) 60psig	Total Equivalent Energy (MBtu/BD ton)	Total Energy Which is Electricity (%)	Recovered Steam (MBtu/BD ton)	Net Equivalent Energy Consumed (MBtu/BD ton)
Pulp Mill							
Roundwood Barking (Friction)	15.3		--	52	100	1,705[b]	(1,653)[f]
Roundwood Barking (Hydraulic)	23.9		--	82	100	1,705[b]	(1,653)
Roundwood Chipping	25.8		--	88	100	284[c]	196
Groundwood Pulping	1,697.		--	5,793	100	--	5,793
Kraft Pulping	325 - 506	10,700	--	11,800 - 12,400	9 - 14	3,600[d]	8,200 - 8,800
NSSC Pulping	555	6,400	--	8,300	23	2,200[e]	6,100
Bleaching, Groundwood Pulp	80	--	24	300	91	--	300
Semi-Bleaching Kraft, Pulp	155	--	4,100	4,600	12	--	4,600
Heavy Bleaching Kraft Pulp	312	--	4,100	5,200	20	--	5,200
Paper and Paperboard Making							
Newsprint	300	--	5,100	6,100	17	--	6,100
Writing Paper	350	--	10,200	11,400	11	--	11,400
Linerboard	325	--	10,200	11,300	10	--	11,300
Medium	325	--	9,600	10,700	10	--	10,700
Folding Boxboard	375	--	10,200	11,500	11	--	11,500
Converting							
Writing Paper	80		--	273	100	--	273
Corrugated Containers	80		1,700	2,000	14	--	2,000

NOTES TO EXHIBIT 26-10

(a) Electric energy is evaluated at 3,413 Btu/kWh

(b) Recovered energy from roundwood barking is based on burning recovered bark in combination boilers. It is assumed that 12.5% of the input roundwood is removed, of which 85% is combustible (the balance being sand, grit and dirt), and thermal energy transferred to steam is based on a 70% boiler efficiency at a higher heating fuel value for the bark of 10.5 MM Btu/ton wet bark (52% water), and a net heating value of 0.92 times the higher heating value.

(c) Recovered energy from chipping is based on burning chip fires in combination boilers. It is assumed that 2% of the input chips is recovered as fires, all of which is combustible, and that thermal energy transferred to steam is based on a 70% boiler efficiency and a higher heating fuel value for the chip fires of 10.5 MM Btu/ton wet chip (52% water) and a net heating value of 0.92 time the higher heating value.

(d) Recovered energy from Kraft pulping is based upon the ligneous solids removed with spent pulping lignors and burned in a recovery furnace with the simultaneous recovery of pulping chemicals. For the estimation of energy recovery in this table, it is assumed that Kraft pulping yield is 50%, recovery furnace efficiency for steam generation is 60% and that the pulping liguor has a higher heating value of 13.2 MM Btu/ton of Kraft solids and a net heating value of 0.92 times the higher heating value.

(e) Recovered energy from NSSC pulping is based on the ligneous solids removed with spent pulping lignors. Steam generation and spent pulping chemical regeneration is recovered with Kraft pulping wastes in mills having integrated NSSC/Kraft pulping. The recovery figure in this table is pro-rated for NSSC pulping assuming that NSSC pulp yields are 77% and that cross-recovery with Kraft pulp wastes is done at 60% recovery furnace efficiency and that the NSSC pulping liguor has a higher heating value of 13.2 MM Btu/ton NSSC solids and a net heating value of 0.92 times the higher heating value.

(f) Brackets indicate the net production of energy.

EXHIBIT 26-11

OVERALL MATERIALS AND ENERGY SUMMARY FOR THE PRODUCTION OF 1 TON OF NEWSPRINT IN AN INTEGRATED PAPERMILL IN U.S. IN 1971

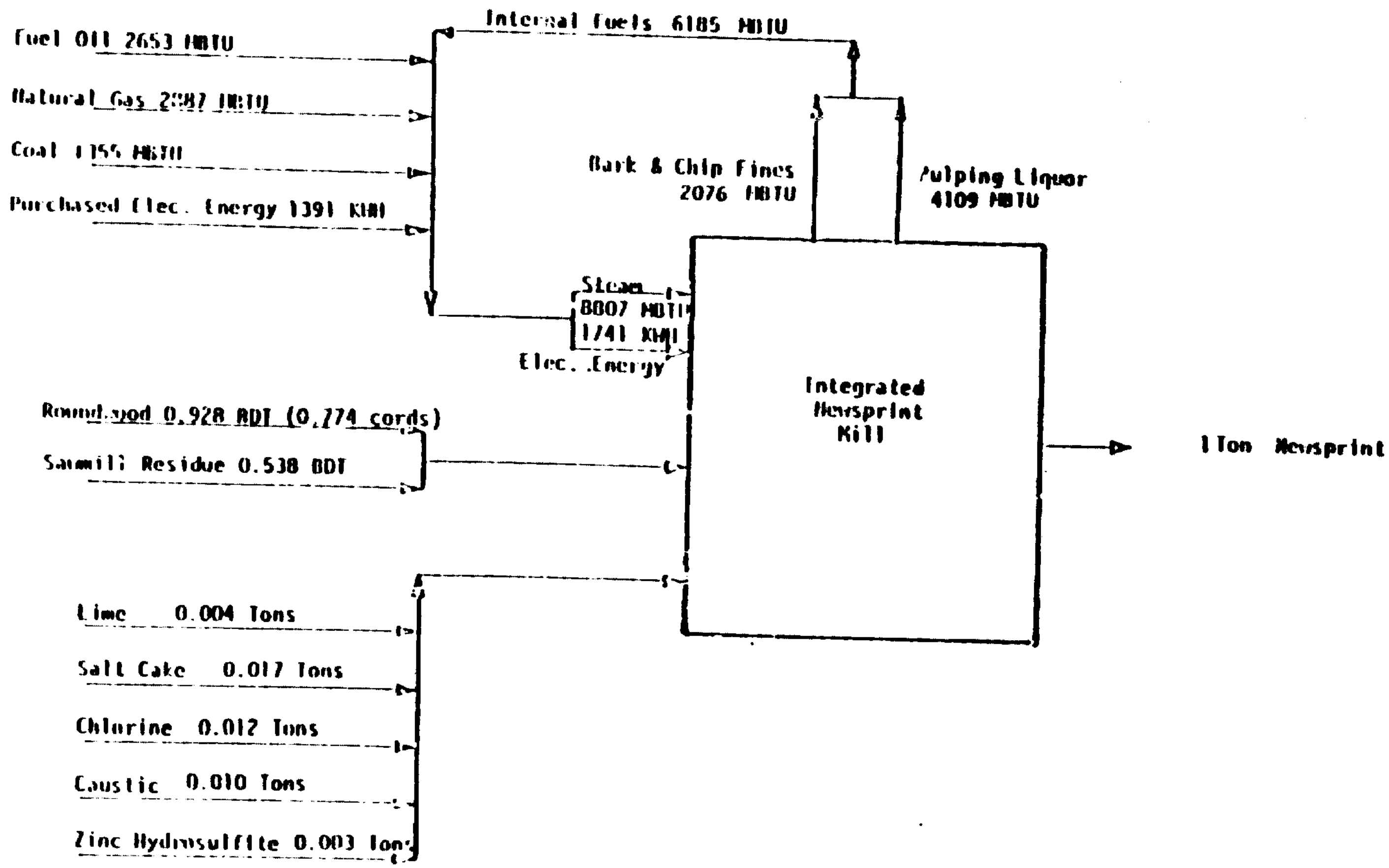


EXHIBIT 26-12

OVERALL MATERIALS AND ENERGY SUMMARY FOR THE PRODUCTION OF 1 TON OF CONVERTED WRITING PAPER IN AN INTEGRATED PAPERMILL IN U.S. IN 1971 (excluding energy for fillers)

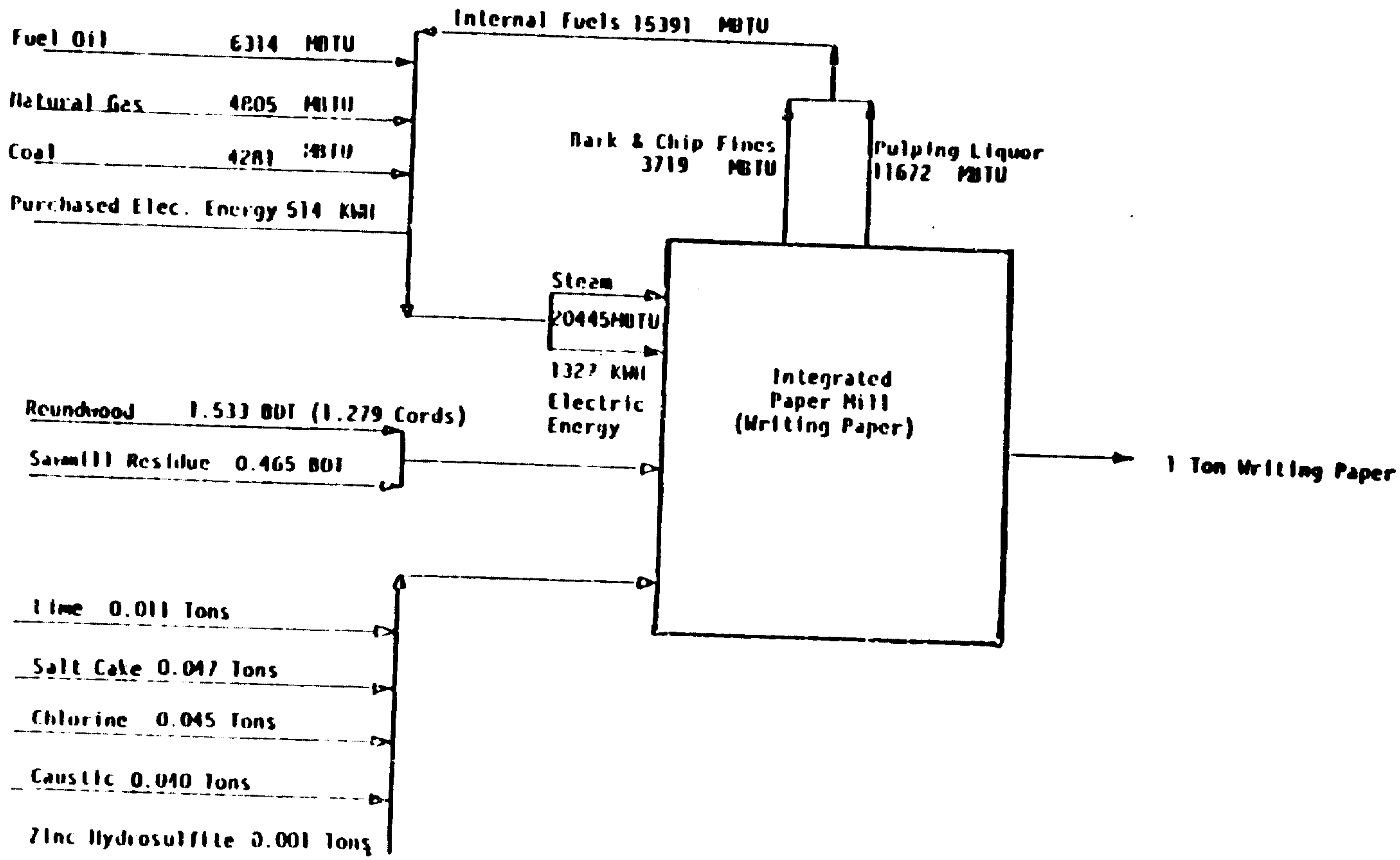


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EXHIBIT 26-13

OVERALL MATERIALS AND ENERGY SUMMARY FOR THE PRODUCTION OF 1 TON OF CONVERTED CORRUGATED CONTAINERS AND THE CONTAINERBOARD REQUIRED TO MAKE 1 TON OF CORRUGATED CONTAINERS IN U.S. IN 1971

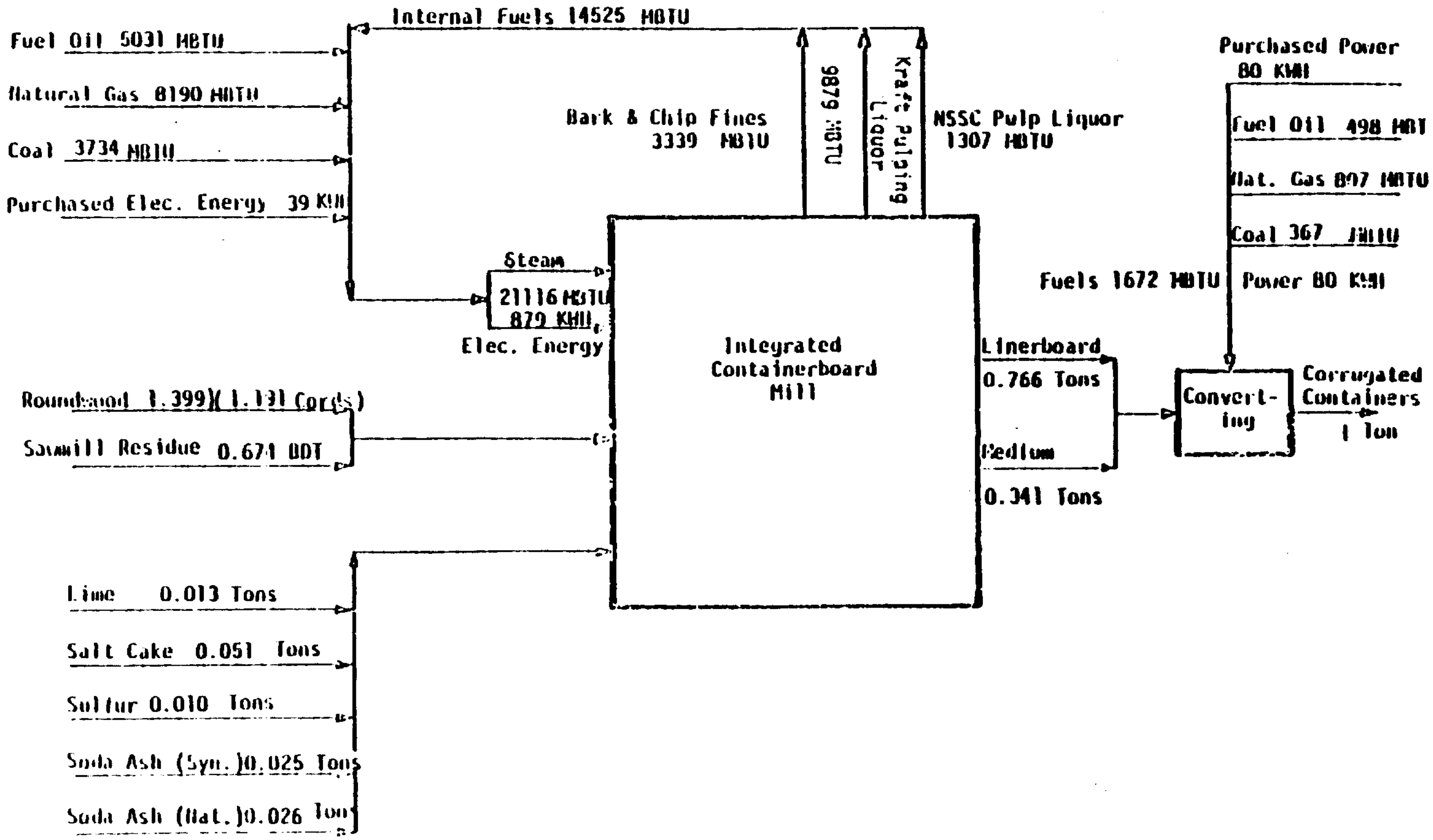

EXHIBIT 26-14

OVERALL MATERIALS AND ENERGY SUMMARY FOR THE PRODUCTION OF 1 TON OF FOLDING BOXBOARD IN AN INTEGRATED PAPERBOARD MILL IN U.S. IN 1971

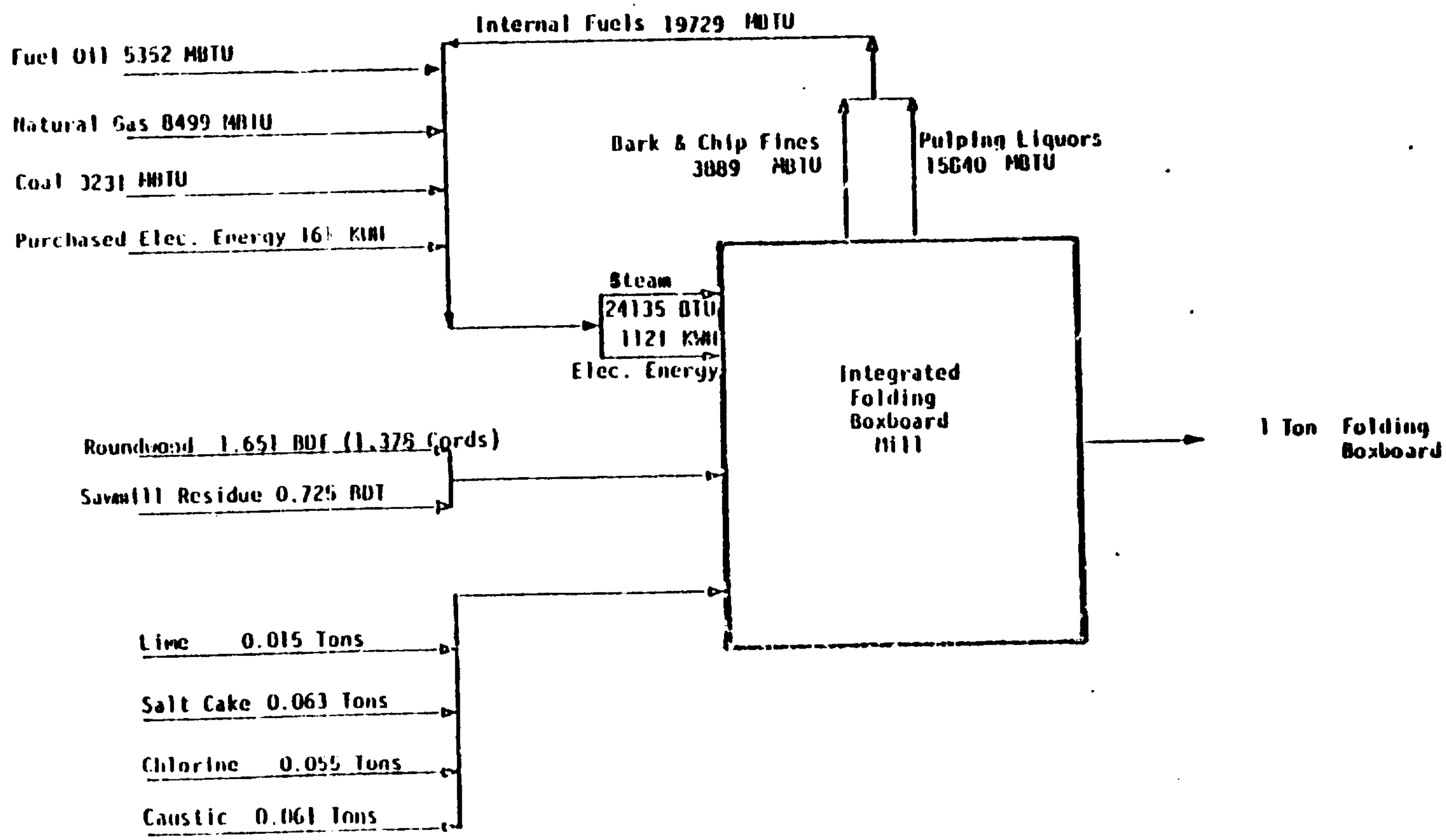

EXHIBIT 26-15

ANNUAL NATIONAL DATA (1975) FOR SELECTED PAPER AND PAPERBOARD PRODUCTS[a]

Product	Production (10^3 tons)	Total Energy Consumption (10^{12} Btu)[b]	Purchased Electricity (10^{12} Btu)[b]	Purchased Fuels (10^{12} Btu)	Purchased Coal (10^{12} Btu)	Fossil Fuels[c] Oil (10^{12} Btu)	Gas (10^{12} Btu)	Other Fuels (10^{12} Btu)	On-site Electricity Generation (10^{12} Btu)	Total Energy Consumption For SIC 26 (10^{12} Btu)	Percent Total Energy Consumption Represented
Newsprint	3,476	62	16.5	24	4.7	9.2	10.0	21.5	4.2	1293.6	4.8
Writing Paper	3,244	106	5.7	50	13.9	20.5	15.6	49.9	9.0	1293.6	8.1
Corrugated Containers	14,846	498	6.0	277	60.9	82.1	133.6	215.6	42.6	1293.6	38.5
Folding Boxboard	2,918	109	1.6	49.9	9.4	15.6	24.8	57.6	9.6	1293.6	8.4

a All data in this exhibit are estimated, with the exception of 1975 production of each product and total energy consumed by all of SIC 26.

b Electricity, as part of total energy consumption and as purchased electricity, is rated at 3413 Btu/kWh.

c Breakdown of purchased fuels into type for each product is based on mills using regional available chips and roundwood and fossil fuel use on a regional basis; newsprint mill in the south, linerboard mill in the south and converting in the northwest (for corrugated containers), SBS folding boxboard mill in the south, writing paper mill in the south.

d Other fuels specifically refers to on-site generated combustible wastes; chip fires and pulping liguors.

EXHIBIT 26-16

ENERGY CONSUMPTION PER TON OF PRODUCT FOR SELECTED PAPER AND PAPERBOARD PRODUCTION SYSTEMS[a]

Product	Electricity[e] (10^6 Btu/ton)	Hot Water (10^6 Btu/ton)	Steam Consumed (10^6 Btu/ton) To 300°F	300-500°F	Over 500°F	Direct Fuel[c] (10^6 Btu/ton)	Exhaust Steam[d] Temperature °F	Energy Content (10^6 Btu/ton)
Newsprint	5.9	(b)	2.7	6.1	--	--	--	--
Writing Paper	4.5	(b)	7.3	13.2	--	--	--	--
Corrugated Containers	3.0	(b)	10.1	11.0	--	--	--	--
Folding Boxboard	3.8	(b)	10.3	13.8	--	--	--	--

(a) All data in this exhibit are estimated from production energy requirements from Exhibits P-1 through P-4 and P-11 through P-14.

(b) Profuse quantities of hot water are used for pulp washing but exact amounts are generally not available. To a first approximation, hot water usage may be considered equal to the total quantity of steam generated. Assuming 1100 Btu/lb of steam raised, the approximate number of pounds of hot water used per ton of product would be as follows:

Product	Hot Water Usage (lb/ton product)
Newsprint	8,000
Writing Paper	11,000
Corrugated Containers*	19,000
Folding Boxboard	22,000

Effluent wastewater temperatures are low, about 100° F. The corresponding enthalpy is about 68 Btu/lb.

(c) Fuel by-product credits are as follows:
6.2 x 10^6 Btu/ton newsprint
15.4 x 10^6 Btu/ton writing paper
14.5 x 10^6 Btu/ton corrugated containers
19.7 x 10^6 Btu/ton folding boxboard

(d) Most steam is condensed in process applications and used as hot water for pulp washing and for boiler feed water.

(e) Electricity evaluated at 3413 Btu/kWh.

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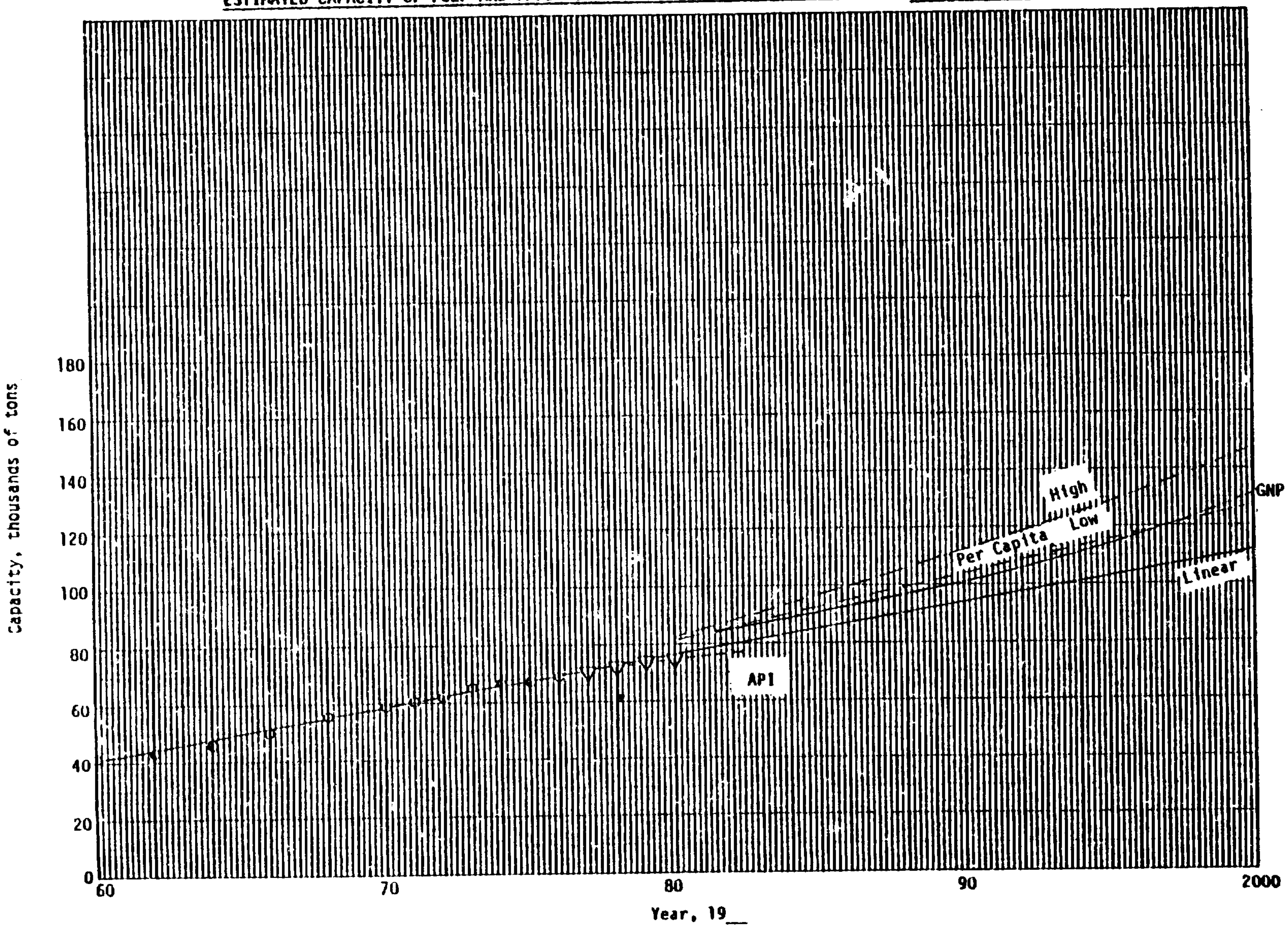
* Does not include steam usage at the converting mill.

ESTIMATED CAPACITY OF PULP AND PAPER INDUSTRY PRODUCTS, 1978-2000 EXHIBIT 26-17



NOTES TO EXHIBIT 26-17

(1) Growth estimates based on GNP. Consumption of pulp and paper industry products has tracked the GNP since 1955 at an average of 53.4 M tons per billion dollars of real GNP[a]. The growth curve shown is based on 1978 GNP of 1390 billion dollars, an estimated annual compound GNP growth rate of 2½% to the year 2000, and a constant ratio of pulp and paper industry annual consumption to the real GNP.

(2) Growth estimates based on per capita consumption. From per capita consumption of total paper and paperboard in the U.S.[b] for the period 1955 -1973, a time series was developed which was used to predict per capita consumption to the year 2000.

Year	Per capita consumption (lb/capita from extrapolated time series
1980	734
1985	811
1990	888
2000	1042

These per capita consumptions were then combined with high and low population estimates in the same years[c].

(3) Linear growth rate. A least square time series was developed from API data[a] for the total capacity of all paper and paperboard produced in the U.S. from 1960 to 1976 and then extrapolated to the year 2000.

(4) API growth rate. Capacity of all paper and paperboard in the U.S. for the years 1977 to 1980 are reported by the API[d].

(a) "Statistics of Paper and Paperboard, 1977", p. 65, American Paper Institute, New York, N.Y., October, 1977.

(b) ibid

(c) "The Statistical Abstract of the U.S.", p. 6, Bureau of the Census, Department of Commerce, October 1977.

(d) "Paper, Paperboard, Woodpulp 19761979 Capacity", p. 3, American Paper Institute, New York, N.Y., 1977.

EXHIBIT 26-18

PULP AND PAPER/PAPERBOARD MILL PLANT FACTORS

Product	Typical Plant Capacity[a] (M tons/year)	Electric Load Factor	Thermal-Electric Coincidence Factor	Projected Applicability to 2000
Newsprint	600	greater than	1.0	(a)
Uncoated Free Sheet[b]	200	0.9		
Unbleached Kraft[c]	750			
Semi-Chemical[c]	375			
Solid Bleached Sulfate[d]	500			

(a) Electric load factor and thermal-electric coincidence factor should stay high out to this time period. Plant capacities and size ranges in each category are difficult to estimate, except to note that, in general, individual plant capacities have steadily increased to take advantage of economics of scale.

(b) The general classification "writing paper" includes many different kinds of paper products the largest of which is uncoated free sheet. Typical plants of this sub-classification are of the size shown.

(c) Some plants produce unbleached Kraft linerboard and semi-chemical medium simultaneously, although these materials are also produced in separate plants. However, converting to corrugated containerboard is always done at a separate site. Since sizes shown relate to typical linerboard and medium plant capacities, it may be assumed that the size of a typical converting plant would be equivalent to the sum of 750 and 375, or 1125 thousand tons per year.

(d) Although folding boxboard may be produced from recycled paper, unbleached Kraft, or solid bleached sulfate (SBS) board, SBS is used herein as a surrogate for folding boxboard since most folding boxboard is made from SBS. The typical sizes of these plants are likely to be similar.

EXHIBIT 26-19

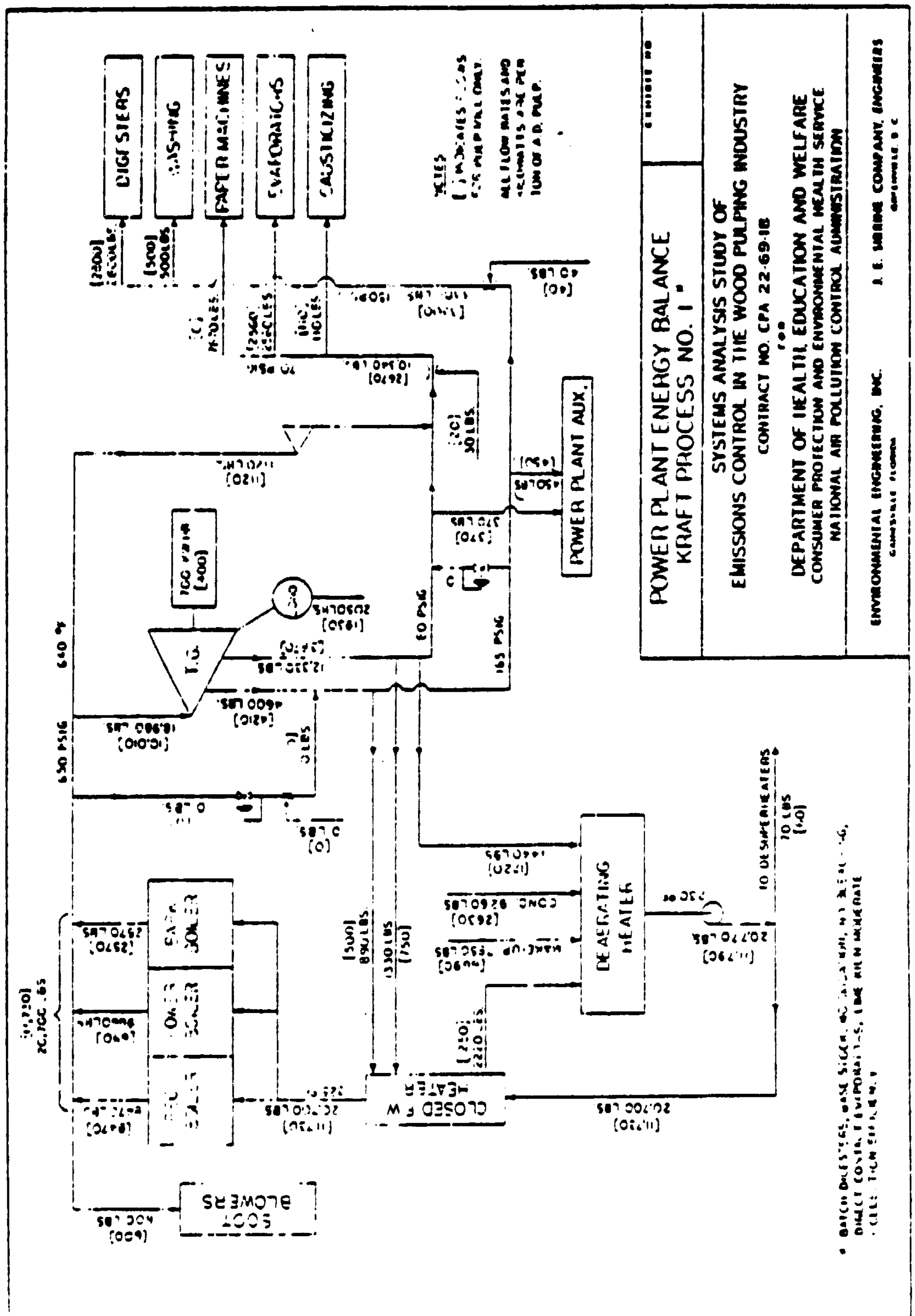


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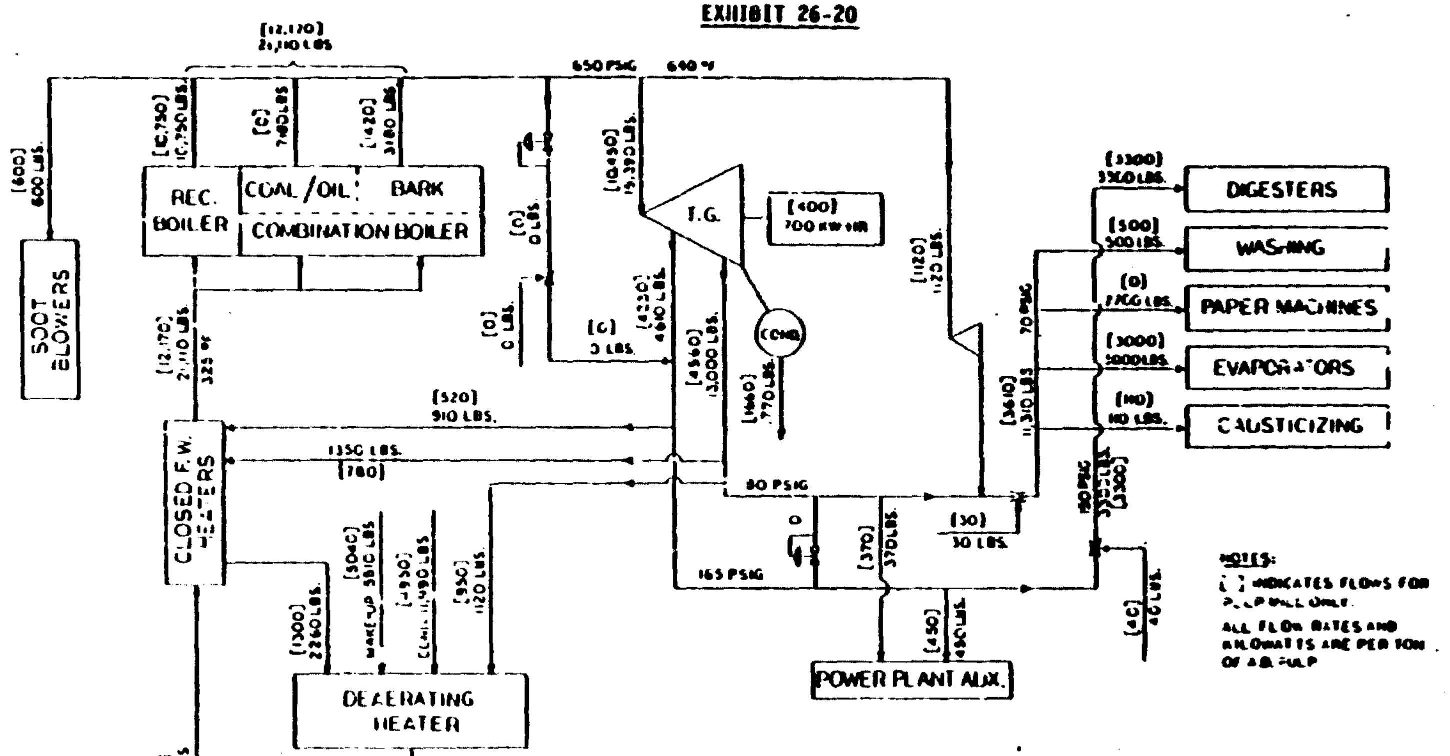
EXHIBIT 26-20



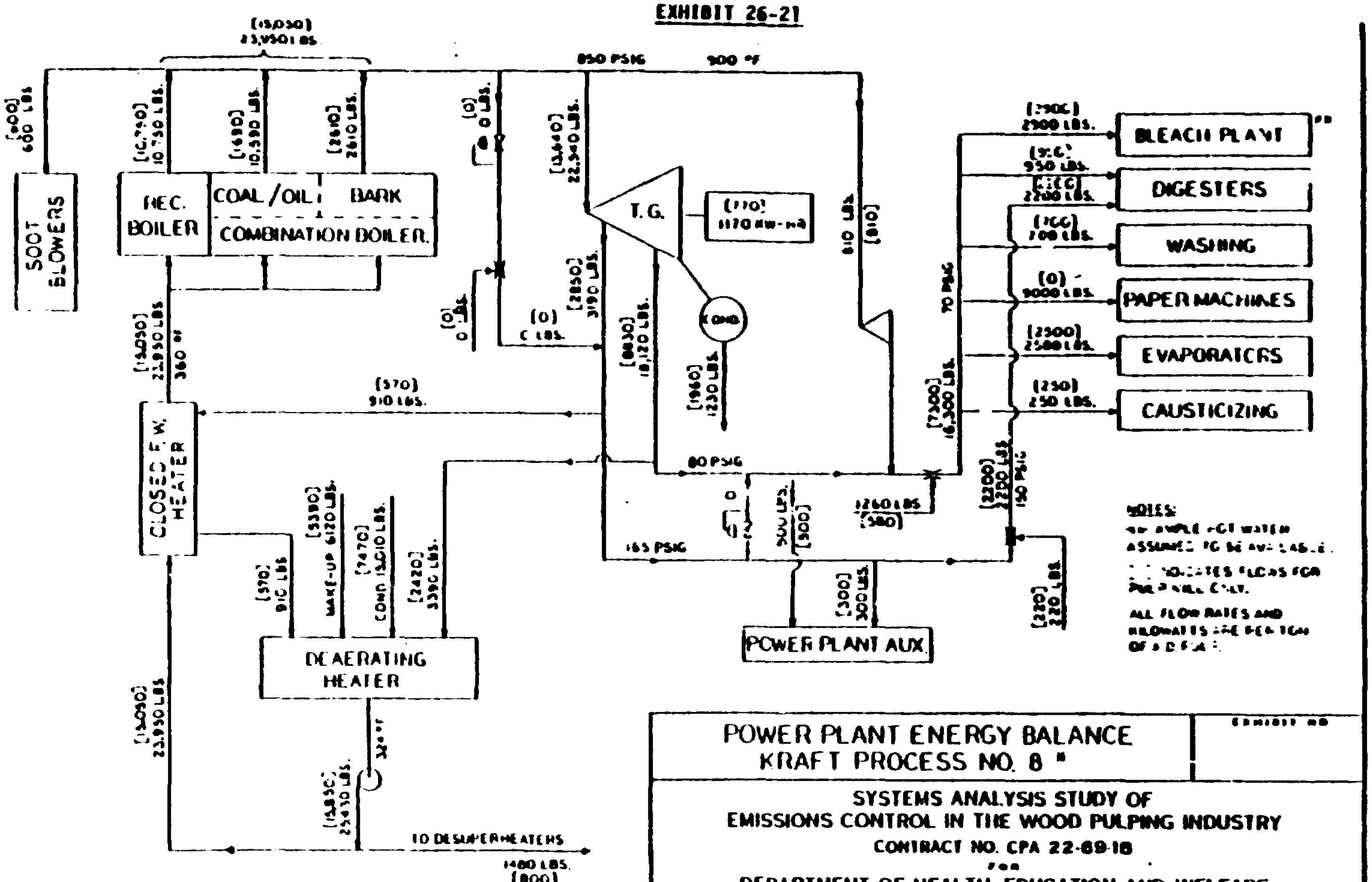
* TOP LINER OR PAPER STOCK, BATCH DIGESTERS, NO OXIDATION, DIRECT CONTACT EVAPORATOR RECOVERY, NO BLEACHING, AND LIME KILN MODERATE COLLECTION EFFICIENCY.

POWER PLANT ENERGY BALANCE KRAFT PROCESS NO.5 *	EXHIBIT NO

SYSTEMS ANALYSIS STUDY OF
EMISSIONS CONTROL IN THE WOOD PULPING INDUSTRY
CONTRACT NO. CPA 22-69-18
FOR
DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
CONSUMER PROTECTION AND ENVIRONMENTAL HEALTH SERVICE
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

ENVIRONMENTAL ENGINEERING, INC. — GAINESVILLE, FLORIDA
J. E. SIRRINE COMPANY, ENGINEERS — GREENVILLE, S. C.

EXHIBIT 26-21



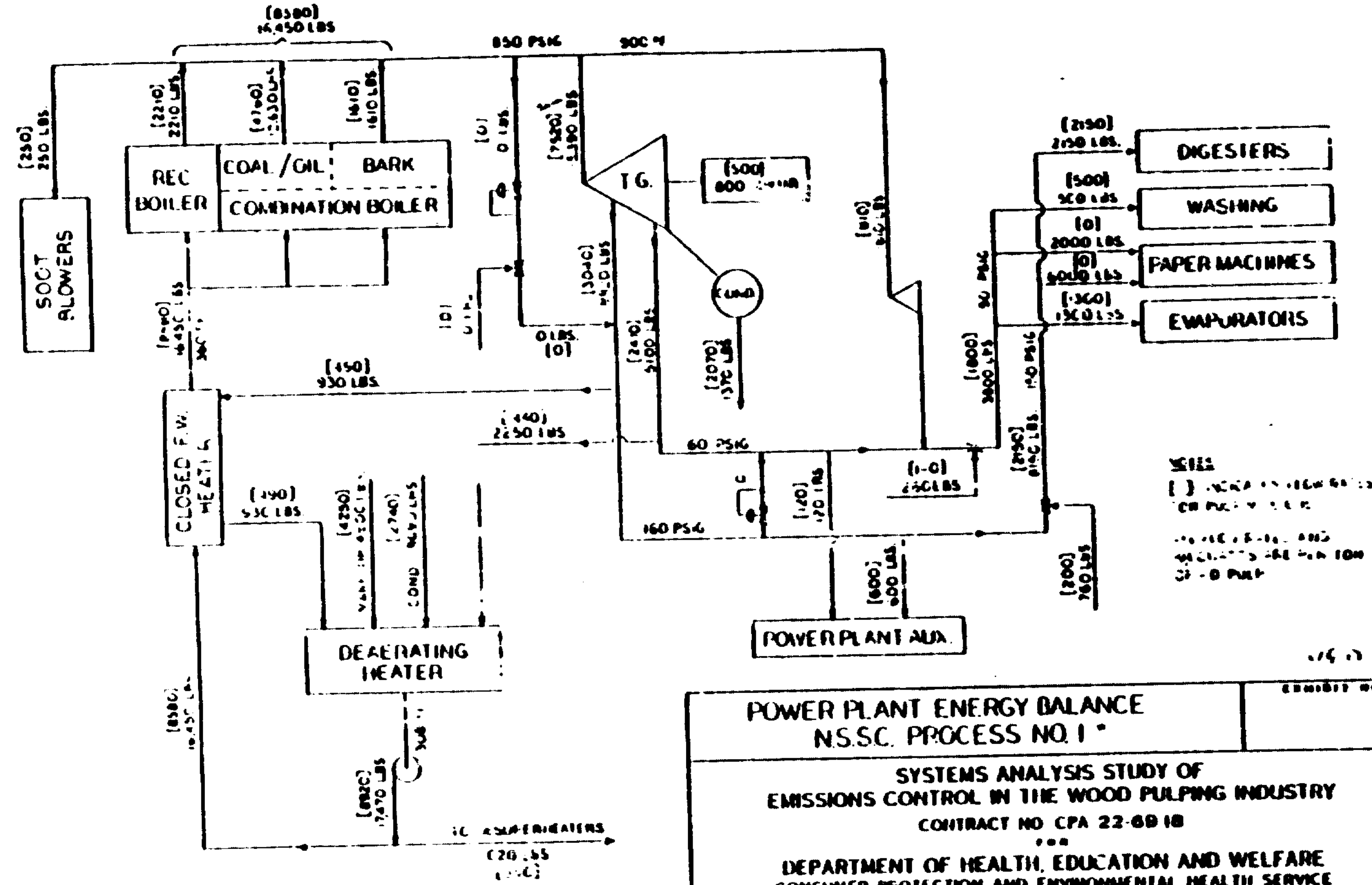
POWER PLANT ENERGY BALANCE KRAFT PROCESS NO. 8 *	EXHIBIT NO.

SYSTEMS ANALYSIS STUDY OF
EMISSIONS CONTROL IN THE WOOD PULPING INDUSTRY
CONTRACT NO. CPA 22-69-18
FOR
DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
CONSUMER PROTECTION AND ENVIRONMENTAL HEALTH SERVICE
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

ENVIRONMENTAL ENGINEERING, INC. — GAINESVILLE, FLORIDA
J. E. SIRRINE COMPANY, ENGINEERS — GREENVILLE, S. C.

* CONTINUOUS DIGESTERS, HARDWOOD, NO LIQUOR OXIDATION, DIRECT CONTACT EVAPORATOR RECOVERY, BLEACHING, AND LIME KILN HIGH COLLECTION EFFICIENCY.

EXHIBIT 26-22



* COMBINATION OF NEUTRAL SULFITE SEMI CHEMICAL PULPING AND KRAFT PULPING.

POWER PLANT ENERGY BALANCE N.S.S.C. PROCESS NO. 1 *	EXHIBIT NO

SYSTEMS ANALYSIS STUDY OF
EMISSIONS CONTROL IN THE WOOD PULPING INDUSTRY
CONTRACT NO CPA 22-69-18
FOR
DEPARTMENT OF HEALTH, EDUCATION AND WELFARE
CONSUMER PROTECTION AND ENVIRONMENTAL HEALTH SERVICE
NATIONAL AIR POLLUTION CONTROL ADMINISTRATION

ENVIRONMENTAL ENGINEERING, INC. — J. E. SIRRINE COMPANY ENGINEERS

EXHIBIT 26-23

NEW BOILER INSTALLATIONS IN THE PULP AND PAPER INDUSTRY (1965 - 1975)

Operating Pressure (psig)	Number of Boilers	Capacity (10^9 lbs/year)
<150	43	15
150-250	173	88
250-350	60	40
350-450	51	69
450-600	33	57
600-850	117	210
850-1250	90	270
>1250	26	100
	593	850

Source: "A Study of Inplant Electric Power Generation in the Chemical, Petroleum Refining and Paper and Pulp Industries", Thermo Electron Corporation.

EXHIBIT 26-24

TOTAL STEAM BOILER CAPACITY IN THE PULP AND PAPER INDUSTRY (1975)

Capacity (10^9 lbs/year)

Region	Pressure (psig)								Total
	<150	150-250	250-350	350-450	460-600	600-850	850-1250	>1250	
New England	18	15	.54	4.7	8.7	41	23	29	140
Middle Atlantic	24	30	1.6	30	2.9	52	24	--	160
East North Central	40	36	19	24	33	89	9.0	19	270
West North Central	1.9	9.0	---	---	---	23	---	16	50
South Atlantic	16	4.2	5.9	3.8	39	160	170	9.2	410
East South Central	3.3	24	---	9.5	4.3	62	94	--	200
West South Central	8.6	8.7	9.1	---	18	54	87	28	210
West	11	60	26	13	25	110	12	--	260
USA	120	190	63	86	130	90	420	100	1700

Source: "A Study of Inplant Electric Power Generation in the Chemical, Petroleum Refining and Paper and Pulp Industries', Thermo Electron Corporation.

CHLORINE/CAUSTIC PRODUCTION

1.0 PROCESS IDENTIFICATION

This section identifies and specifically defines the industry, and provides a brief description of the current production processes employed.

1.1 SIC Classification

The production of chlorine/caustic is classified under SIC code 2812, which covers "establishments primarily engaged in manufacturing alkalies and chlorine." Other major products of SIC 2812 which are not included in this study are soda ash, potash and sodium bicarbonate.

1.2 Process Description

Chlorine is manufactured almost entirely by the electrolysis of saturated brine solution. Two types of electrolytic cells dominate the industry, namely the diaphragm and mercury cells. The diaphragm design is estimated to account for more than 70% of U.S. chlorine production and is described below. A process flow diagram, illustrating inputs and outputs of materials as well as the various unit operations involved in the process, is provided in Exhibit 2812-1.

Solid salt is dissolved in water to form a saturated solution that is combined with recycled brine not electrolyzed in the process. The brine is treated with alkali (sodium hydroxide/carbonate) to precipitate calcium, magnesium and other metal ions, and then filtered. The brine then passes into the anode compartment of the cell, which operates at approximately 200°F. Modern cells are equipped with a steel cathode and noble metal

(or oxide) coated titanium anode. Older cell designs incorporate graphite anodes. The anode and cathode compartments are separated by an asbestos or acid resin diaphragm. The basic chemistry of the cell is described by the following reaction:

$$2\ NaCl + H_2O \xrightarrow{\text{electrolysis}} 2\ NaOH + H_2 + Cl_2$$

Chlorine is produced at the anode, and hydrogen and caustic soda at the cathode. The purpose of the diaphragm is to minimize the migration of hydroxyl ions into the anode compartment, since this migration results in undesirable side reactions and shorter anode life.

Hydrogen is cooled and scrubbed by direct contact with water and then used for fuel or possibly other chemical use. Chlorine is cooled and scrubbed with water and then dried by contact with concentrated sulfuric acid. Effluent water is steam stripped to remove chlorine before disposal. Dried chlorine is liquefied by compression and stored in drums and cylinders.

Dilute caustic soda solution (about 10-12 wt%) is withdrawn from the cathode compartment together with unconverted brine. The solution is concentrated to approximately 50% caustic soda content by passing through a multiple effect vacuum evaporator. As the solution concentrates, sodium chloride and sulfate precipitate from solution and are separated in settling drums between each evaporation stage. The solid sodium chloride recovered is washed to remove sodium sulfate and then dissolved to give a brine solution which is recycled to the cell. The process produces 99% wt pure chlorine and 50% wt caustic soda containing around 1% residual sodium chloride.

The competing mercury cell differs from the diaphragm cell in that the cathode consists of a moving bed of mercury. Instead of forming hydrogen and caustic soda in the cell itself, the reaction at the cathode forms mercury/sodium amalgam. This is removed from the cell and decomposed in a separate chamber by contact with water to yield hydrogen and caustic soda. Mercury is recycled to the cell.

Until the last few years, certain advantages of the mercury cell suggested that this design would gradually supercede the diaphragm cell. The caustic soda produced in the mercury cell is of superior quality ($<$ 0.1% vs. 1% sodium chloride) and requires much less steam for concentration. However, the developments of recent years have reversed the trend. The major event has been the recognition of the environmental and health problems association with mercury cells. In addition, recent advances in diaphragm cell design promise to provide considerably improved performance. The most important development is the replacment of the conventional asbestos diaphragm by acid resin membranes. These minimize migration of the cathode ions into the cathode compartment and result in the production of higher purity caustic soda with low ($\sim$ 0.2% wt) sodium chloride content. Caustic soda withdrawn from the cathode compartment is more concentrated than from the conventional cell, resulting in lower energy requirements for evaporation. These developments will probably ensure that the diaphragm cell remains the dominant design in the U.S.

2.0 NATIONAL DATA

The annual national data presented in this section are summarized in Exhibit 2812-2. The derivation and significance of the production and energy consumption data are discussed in the following sub-sections.

2.1 Capacity and Production Data

Total U.S. chlorine production capacity as of January 1, 1978 was 13.7 million tons annually, up from 13.0 million tons a year ago.[1] Annual production in 1978 is projected to reach 11.1 million tons, compared with 10.7 million tons in 1977[1].

There are approximately thirty corporations in the U.S. producing chlorine at more than seventy locations across the country. The locations of these facilities are illustrated in Exhibit 2812-3. Plant sizes range from small 2,000 ton/year plants captive to the paper industry (where chlorine is used for bleaching) to over 2 million tons/year of capacity at Dow Chemical's Freeport, Texas facility. Neglecting the numerous small captive producers, the typical size of a merchant chlorine-producing facility in the U.S. is currently about 150,000 tons per year. This is reflective of the size of plants built during the period 1960-1975. The average production capacity of plants built since 1975 (of which there are five) is by contrast, roughly 365,000 tons per year.

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(1) "Chlorine, Major Alkalies Still in Doldrums", Chemical & Engineering News, Feb. 6, 1978, p.9.

2.2 Annual Energy Consumption

The U.S. Census Bureau reports the following consumption of energy in 1975 by SIC code 2812:(1)

1975 ENERGY CONSUMPTION, SIC 2812

ENERGY SOURCE	CONSUMPTION
Fuel oil	4.33×10^{12} BTU
Coal	53.04×10^{12} BTU
Natural gas	53.21×10^{12} BTU
Purchased electricity	$11,764.5 \times 10^{6}$ kWh
Self-generated electricity*	2517.1×10^{6} kWh

* Fuels used to generate electricity on-site are already included in the individual fuel consumptions above.

As explained in section 1.1, chlorine and caustic are not the only products of SIC 2812, and an adjustment is required in order to more accurately assess the quantity of energy consumed in producing these two chemicals. The FEA "target" document for this industry estimates that, of the total energy consumed in SIC code 2812, 85.2% is for the production of chlorine/caustic(2). Applying this percentage to the table above results in the following estimates of energy consumed during 1975 in the production of chlorine/caustic:

(1) U.S. Dept. of Commerce, "Annual Survey of Manufactures", Fuels and Electric Energy Consumed, 1975 edition.

(2) Battelle Columbus Laboratories, "Developing a Maximum Energy Efficiency Improvement Target for SIC 28", Federal Energy Administration, July 1, 1976.

ENERGY CONSUMED IN CHLORINE/CAUSTIC PRODUCTION, 1975

ENERGY SOURCE	CONSUMPTION
Fuel oil	3.69×10^{12} BTU
Coal	45.19×10^{12} BTU
Natural Gas	45.33×10^{12} BTU
Purchased Electricity	$10{,}023.35 \times 10^{6}$ kWh
Self-Generated Electricity*	2144.57×10^{6} kWh

* Fuels used to generate electricity on-site are already included in the individual fuel consumptions above.

3.0 PROCESS ENERGY REQUIREMENTS

The sub-sections which follow describe in depth the energy consumed per unit of production in chlorine/caustic manufacture, as well as providing detail on the type of energy required. A summary of the energy requirements per unit output appears in Exhibit 2812-4.

3.1 Unit Energy Consumption Data

The electrochemical production of chlorine is an electricity-intensive operation, requiring electric current to decompose an aqueous electrolyte into products.

The quantity of production is a direct function of the amount of current passed through the cell. Thus, if the amperage and current efficiency are known, it is possible to calculate the daily production rate. A current of 1 ampere produces about 0.08 lbs. of caustic and 0.07 lbs. of chlorine per day, theoretically. A 30,000 ampere cell, for example, has a theoretical capacity of 2100 lbs. of chlorine per day. If the cell operates at 95% efficiency, the capacity of the cell is one ton of chlorine per day.

Industry representatives cite present electricity requirements to be approximately 3000 kwh (AC)[1] per electrochemical unit (E.C.U.)[2] with the diaphragm cell, versus about 3400 kwh (AC) per E.C.U. with the mercury

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(1) There is roughly a 3% loss in converting AC to DC, using solid state rectifiers. Mercury-arc rectifiers (used before 1968) are characterized by a 9% loss.

(2) An electrochemical unit is 1.0 ton of chlorine plus 1.12 tons of caustic in 50% solution.

cell, with non-consumable (metal) anodes[1]. Older cells still using graphite anodes reportedly consume 10-20 percent more electricity. Diaphragm cells also require about 7500 lb. of steam per E.C.U. for caustic concentration, whereas mercury cells yield caustic which does not generally require further concentrating, i.e., there is virtually no steam required for evaporation. Thus, on the basis of total BTU's consumed, diaphragm cells consume more energy than do mercury cells, for equivalent outputs.

The ancillary equipment necessary for operations upstream and downstream of the cell also requires energy: brine must be purified and heated; chlorine gas must be collected and pumped to collecting tanks for further processing by cooling, drying, refrigeration and liquefaction. Hydrogen off-gas is also collected from the cell structure, and the caustic solution must be drawn from the cell. Gas-evacuating and ventilating systems are also necessary to prevent an explosive reaction from taking place between the gases. The energy used in all phases of the production process is summarized in Exhibit 2812-5.

3.2 Details of Electricity Consumption

Chlorine plants operate continuously, 24 hours a day, generally with load factors in excess of 90%. Although the relative quantity of heat loss is greater at higher production levels, the overriding tradeoff in plant design is between capital and operating costs. Hence, high production rates are characteristic of the industry and load factors exceed 95% in many cases.

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(1) Similar data are available in the literature, e.g. "Energy Use Patterns in Metallurgical and Nonmetallic Mineral Processing" Phase 4, National Technical Information Service, June, 1975, p.34.

As seen from Exhibit 2812-5, about 90% of the electric energy is consumed in the electrolysis cells in the form of D.C., with the remaining 10% supplied as A.C. The cells themselves operate on a cell-to-cell voltage of about 3-4 volts, with about 30,000 amperes required per ton of chlorine. Cells are connected in series, with production control exercised through current variation. In a typical cell, amperage is approximately zero at 2.3 volts and at design limits at around 3.3 volts.

As previously mentioned, electric energy consumption is essentially constant, with the only major maintenance interruptions being for replacement of cell diaphragms. Cells operating with the older graphite anodes and asbestos diaphragms have a typical run length of 70-90 days, whereas metal anodes can prolong run lengths to a year. Hooker claims that the new acid resin membranes can be expected to have a life of around two years.

Start-up presents no voltage overload problems, as pumps, compressors and other drivers represent a relatively small portion of the total load. Normal start-up practice is to bring the cells up to one-third capacity relatively quickly and then to full capacity over a period of several hours.

3.3 Details of Thermal Energy Consumption

Thermal energy consumption in chlorine/caustic production is limited to steam usage and there is no direct application of fired heaters. The bulk of the steam (about 80%) is used for caustic soda evaporation, which is usually performed in a triple effect evaporator. Input steam is required at about 90 psi, and as shown in Exhibit 2812-5, the amount needed is about 7500 lbs per unit output. About 1900 lbs of low pressure steam (around 30 psi) is needed for brine purification and heating.

In a conventional triple effect evaporator, the first two stages operate at about 140°F and 200°F. The third stage usually operates at over 300°F. Typically, all the process steam is used in the third stage, with the steam evaporated from the caustic soda solution utilized to provide thermal energy to the first and second stages.

As with electric energy consumption, steam consumption is essentially constant over the entire year.

An energy credit accrues to the chlorine/caustic production process as a result of the by-product hydrogen produced. For every ton of chlorine produced, 56 pounds of hydrogen are generated, representing 2.9×10^6 BTU at the net heat of combustion of 51,600 BTU/lb. In current practice, this gas is typically vented or flared, and only about 25% is currently utilized beneficially.

4.0 ANTICIPATED TRENDS

This sectio[illegible] [illegible]cusses the trends which are likely to occur in the industry through the year 2000. The major emphasis is on three areas: marketing, process technology, and energy consumption.

4.1 Product Growth Trends

Caustic soda and chlorine rank third and fourth, respectively, in volume of shipments of inorganic chemicals in the U.S., topped only by sulfuric acid and ammonia. As mentioned in section 2.1, chlorine production in 1978 is expected to reach 11.1 million tons; caustic production will be nearly 12 million tons. Since the quantities of production of both materials are intrinsically linked, future production trends will be identical and will be determined by the one with softer demand. Currently, and for the foreseeable future, demand for chlorine is the dominant production factor. Therefore, the following discussion centers on chlorine.

The end uses of chlorine are relatively well known and well diversified. Major end uses are diverse chemicals (40%), plastics - mostly PVC (20%), solvents (15%), pulp and paper (15%), water treatment and miscellaneous (10%)[1]

There are many issues which will impact upon these major markets, as well as on chlorine itself. The first and perhaps most crucial issue will be the cost and availability of energy. Energy costs now represent over

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(1) "Chlorine, Major Alkalies Still in Doldrums", Chemical & Engineering News, Feb. 6, 1978, p.9.

50% of the manufacturing cost of chlorine[1]. This percentage is likely to rise as old contracts for natural gas phase out and are replaced with more expensive alternatives.

Another item of concern is the continuing impact of government regulations. Currently, about 3-4% of total production is consumed in aerosols, which may be banned entirely. Various chlorinated solvents such as trichloethylene already have restrictions on their use.

In addition, the cost of capital and impact of inflation on this capital-intensive industry are severe. In the past five years, the cost of building a plant has doubled.

In view of the many negative issues facing chlorine, it is unlikely that historical growth rates will be maintained. Indeed, there is evidence that a decline is already underway. During the period 1967-1975, for example, chlorine production grew at an average rate exceeding 8% per year. However, in 1975, production plummeted to about 9 million tons from nearly 10.8 million tons the previous year, and has risen slowly to current levels.

Overall it is estimated that chlorine growth through the year 2000 will average between a low of 3.5%/year and a high of 5.5%/year with a most probable average growth of 4.3%/year[2]. These projections, along with production figures since 1970, are illustrated in Exhibit 2812-6.

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(1) Zapp, G.M. and Hewitt, W.T., "Industry Outlook for Inorganic Chemicals", Chemical Engineering, June 6, 1977, p.129.

(2) Ibid, p.130.

4.2 Process Changes

Until the last few years, certain advantages of the mercury cell suggested that this design would gradually gain on the diaphragm cell. The caustic soda produced in the mercury cell is of superior quality (0.1% vs. 1% sodium chloride) and requires much less steam for concentration. However, the developments of recent years have reversed the trend. The major event has been the recognition of the environmental problems associated with the mercury cells. In fact, the discharge of mercury into waterways has led to the closing down of numerous mercury cells around the world. Mercury cells are likely to be phased out in this country over a period of several years.

It is likely that the industry will be affected by the fuel availability situation. Although no fuel is fired directly in the production process, fossil fuels are used for generating electricity and steam. Based on data reported by the Census Bureau, the chlor-alkali industry has been shifting away from coal and towards natural gas, with very little oil consumption. In 1975, coal supplied 48% of the industry's fossil fuel needs, compared with 61% in 1971. Natural gas also accounted for 48% in 1975, but this represented a substantial increase from its level of 36% in 1971.

In view of the dwindling supplies and rising prices of natural gas domestically, it is apparent that the industry will have to turn elsewhere for its future fuel supplies. Since producers have historically shown a preference for coal over oil, and since the future oil supply situation is likely to parallel the current natural gas situation, it is apparent that coal (or coal-based fuels, depending on the economics) will be the dominant fuel in future chlorine-caustic production. Because there are no technological constraints on the type of fuel used (i.e., fuel is not fired

directly but is used to generate steam and electricity), it is likely that coal may supply up to two-thirds of the industry's fuel needs by the mid-1990's, with gas supplying the remainder.

4.3 Implementation of New Technology

There are several alternative process techniques available for chlor-alkali production, but the most promising for the future appears to be a process utilizing an ion-exchange membrane to effect chemical separation. The membrane cell was developed by Asahi Chemical Co. in Japan (and others in the U.S.) and has been running at a 40,000 metric ton per year plant since April, 1975. Compared with conventional processes, Asahi claims energy savings, and lower capital and operating costs. Asahi reports electric requirements to be 2840 kwh/ton with the membrance cell, which is lower than the consumption data reported in section 3.1 for both mercury and diaphragm cells (3400 and 3000 kwh/ton, respectively)[1]. Steam consumption is reported to be about 1400 pounds per electrochemical unit, which is significantly less than the 7500 pounds of steam previously cited as required with diaphragm cells[1].

Among U.S. producers, Hooker Chemical has developed a membrance cell of their own design. The membrane is non-permeable, permitting osmotic flow only. Currently, the membrane is being run at a 45 ton per day plant in Dryden, Ontario, where the membrane technology has replaced an older mercury cell. Unfortunately, operating data are unavailable at this time.

In contrast to the diaphragm cell which has difficulty in modulating electricity loads due to its need to maintain steady flow characteristics (i.e. constant head and vacuum on the diaphragm), variations in flow rates

(1) Maomi Seko, "The Asahi Chemical Membrane ChlorAlkali Process", presented at the Chlorine Institute's 20th Chlorine Plant Mgrs. Seminar, New Orleans, La., February 9, 1977, p.8.

reportedly do not affect the membrane's performance. Thus, it appears to be adaptable to variations in load. This is an extremely important advantage of membrane cells in terms of the potential offered as a load management opportunity, given the large electricity demand of chlorine plants. In practice, plants could be designed with sufficient over-capacity to allow for reducing production during hours of utility peak loads yet maintain constant daily production levels. However, the cost effectiveness of such design is a function of several parameters including individual utility characteristics and a detailed cost-benefit anlaysis is outside the scope of this study.

According to information received from Hooker Chemical, the new membrane process is significantly more adaptable to retrofitting mercury cell plants than is the diaphragm process, thus reducing the capital investment required. The membrane process also offers reduced energy consumption compared to the diaphragm process (see above discussion) and, perhaps most importantly, offers substantial potential for managment of the utility load by biasing off-peak hours. Thus, given that the industry will be shifting away from mercury cells (a shift already underway in the U.S. and, in fact around the world), there is good reason to believe that a portion of the chlorine produced in the 1980's will be from membrane cell plants. However, the replacement of mercury cell plants (and possibly the displacement of diaphragm cell plants) by membrane cell plants is a decision which will largely be made by the current economics of the situation. It would appear that, certainly by the year 2000, the current 25% of chlorine production capacity ascribed to mercury cells will be converted into membrane cells. In fact, a part

of this conversion is likely to take place before 1985. However, the industry is presently faced with an over-capacity situation, and little new capacity is being planned. Therefore, it is not probable that more than 5% of total capacity will be of the membrance type prior to 1985.

4.4 Trends in Energy Requirements

The FEA "Target" for the chlor-alkali industry is a 7.6% reduction in unit energy consumption by 1980 relative to 1972 energy consumption levels[(1)]. The sensitivity analysis in that document indicates that the improvement could be as high as 13%. Assuming that a 13% reduction relative to present energy consumption levels could be achieved by 1985, and that membrance cells (with unit energy consumption as indicated in section 4.3) account for 5% of production, Exhibit 2812-7 estimates total national energy consumption in 1985 for chlorine-caustic production.

Because of the current energy advantage of the competing technology, it is reasonable to assume that further improvements will continue to be made to the conventional diaphragm cell. The "Target" study cites one plant currently utilizing 5000 pounds of steam per e.c.u. for caustic concentration, or about 6900 lbs./e.c.u. for the total process sequence. If this level of energy consumption is assumed typical of plants operating in the year 2000, along with a commensurate reduction in electricity needs, energy needs for diaphragm plants in the year 2000 can be estimated. Exhibit 2812-7 presents estimates for the industry's energy consumption in 2000, assuming a 15% reduction in membrane cell energy requirements relative to current levels.

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(1) Battelle Columbus Laboratories, "Developing a Maximum Energy Efficiency Improvement Target for SIC 28", Federal Energy Administration, July 1, 1976.

5.0 PLANT-SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements, including indications of load profiles, state conditions, and reliability considerations. Several plant factors are summarized in Exhibit 2812-8.

5.1 Load Profiles

Because of technological constraints restricting variation in diaphragm cell production rates (see section 5.4, "Reliability Considerations"), plants are run at nearly constant rates for 24 hours a day, 7 days a week. Examination of actual load profiles reveals very little variation in demand, with load factors of about 95%. Due to the continuous nature of the entire operation, the need for steam coincides with the electrical requirements. Hence, Exhibit 2812-8 illustrates a thermal-electrical coincidence factor of 1.0, or 100%.

Cells operating with the older graphite anodes and asbestos diaphragms have a typical run length of 70-90 days, whereupon they are shut down completely for rebuilding. Use of newer metal anodes can prolong run length to a year. Use of acid resin membrane cells can result in a cell life of around two years.

5.2 Energy Flow Schematics

A simplified energy flow schematic for the chlorine-caustic production process appears in Exhibit 2812-9. This Exhibit is identical to the block flow diagram (Exhibit 2812-2) with electrical and thermal requirements superimposed. All energy requirements in Exhibit .312-9 relate to one

electrochemical unit of production, i.e. one ton of chlorine plus 1.12 tons of caustic soda, and are illustrative of current energy consumption levels.

5.3 State Conditions and Mass Flows

As previously illustrated in Exhibit 2812-4, the steam utilized for caustic concentration fall in the range of 300-500°F. This amounts to most of the steam required for the total process, or 8.9 million BTU per E.C.U. The remaining 2.2 million BTU is low pressure steam, i.e. less than 300°F.

Mass flows, with reference to processes and materials illustrated in Exhibit 2812-9, are listed below:

PROCESS AND MATERIAL	UNITS PER TON OF CHLORINE[1]
Brine purification	
soda ash	56 pounds
caustic soda	25 pounds
Brine electrolysis	
graphite	6 pounds
asbestos	1.2 pounds
Chlorine cooling/drying	
sulfuric acid	25 pounds

(1) Battelle Columbus Laboratories, "Energy Use Patterns in Metallurgical and Non-metallic Mineral Processing", Bureau of Mines, June, 1975, p.37.

5.4 Reliability Considerations

Power failure in a diaphragm cell plant has numerous effects. To begin with, there is a loss of production and consequent loss of revenues proportionate to the length of power outage plus the time required to bring the plant back into normal operation. The overall technical problem can be "split" between the effect of power outage on the cell itself, and on the associated power-operated equipment such as pumps and ventilating systems. Although interruption in the cell power supply stops the primary operation, some chemical reaction still continues, with liberation of hydrogen. This gas can combine explosively with chlorine under appropriate circumstances; hence, even if the cell's electrolytic action is terminated, the gases must be removed from the cell. This necessitates the full and continuous operation of both pumping and ventilating systems.

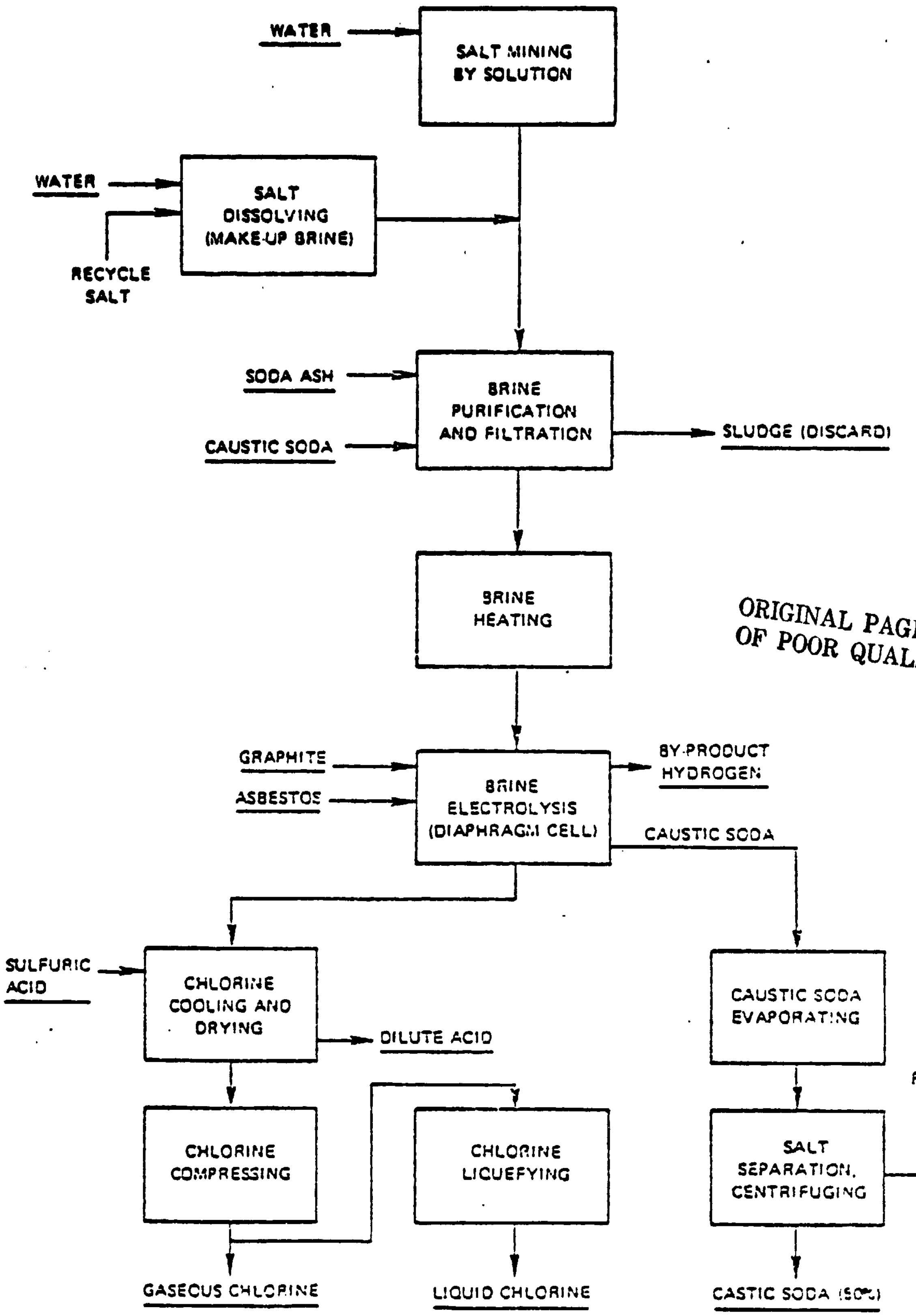
According to industry sources, a total power curtailment to a diaphragm plant might be withstood without unusual damage for about 20 minutes to a half hour. The time required to bring the plant back into normal equilibrium conditions would be on the order of 6 hours. Beyond this time of interruption, the hydrogen problem becomes very severe.

On the other hand, if it is possible to separate the components of total plant load and reduce the power input to maintain ancillary functions to the cell, it may be possible to shed considerable load for longer durations. The need remains, however, to keep the brine circulating, the diaphragms wet, and the accumulating gases pumped out of the cell. Because the diaphragm is held in place by the flow of liquid, it is mandatory to maintain constant flow characteristics within the cell. If the diaphragm

"sloughs off" from its position on the cathode, or is permitted to dry out, the cell must be dismantled and reassembled at high cost and complete loss of production.

In the event of a total curtailment of power to a mercury cell or membrane cell plant, severe problems similar to those described above would occur. However, these types of cells are more flexible in terms of varying rates of production than are diaphragm cells. Mercury plants can be turned down by 10-15% without significant problems, while membrane cells are claimed to be even more adaptable to variation in loads. Hence, in terms of the ability of the process to withstand unexpected changes in power availability, the membrane cell appears to be superior to the more conventional technology.

EXHIBIT 2812-1



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* Battelle Columbus Laboratories, "Developing a Maximum Energy Efficiency Improvement Target for SIC 28", Federal Energy Administration, July 1, 1976.

EXHIBIT 2812-2

ANNUAL NATIONAL DATA (1975), CHLORINE/CAUSTIC INDUSTRY

Product Production - Million Ton	Total Energy Consumption Trillion Btu	Purchased Electricity - Trillion Btu	Purchased Fuels Trillion Btu	Coal	Oil	Gas	Other	Total Energy Consumption For SIC Trillion Btu	Percent Total Energy Consumption Represented
9.1	128.4*	34.2*	94.2	45.2	3.7	45.3	--	150.7	85.2

* Purchased electricity converted to Btu at 3413 Btu/Kwh.

EXHIBIT 2812-3

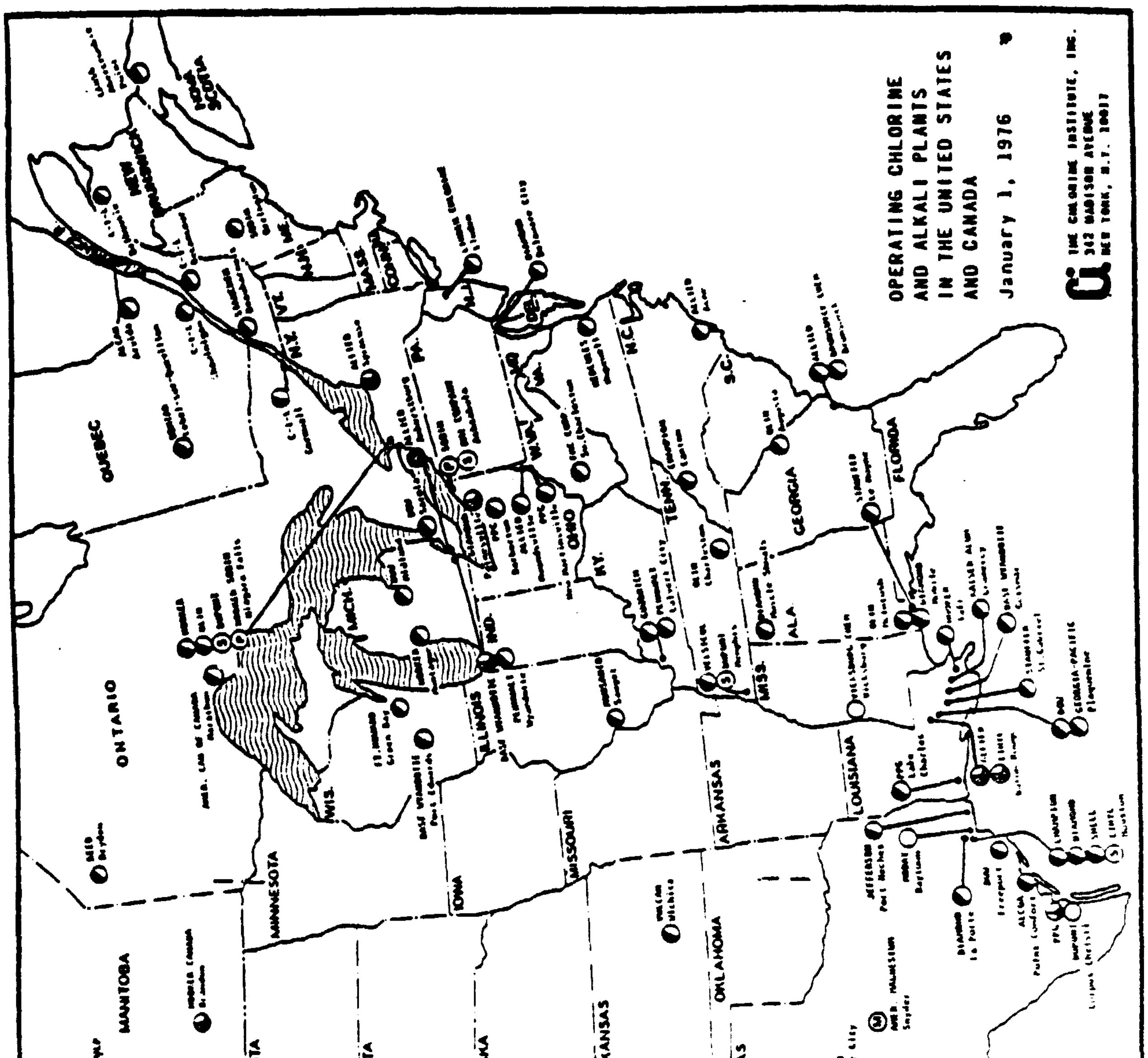

EXHIBIT 2812-4

ENERGY CONSUMPTION PER UNIT OUTPUT* IN CHLORINE/CAUSTIC PRODUCTION - DIAPHRAGM CELL OPERATION

Electricity Million Btu Per Unit	Hot Water Million Btu Per Unit	Steam (Million Btu/Unit)			Direct Fuel*** Million Btu Per Unit	Exhaust Stream	
		To 300^oF	300-500^oF	Over 500^oF		Temperature ^oF	Energy Million Btu Per Unit
11.5**	--	2.2	8.9	--	--	--	--

* unit output denotes one ton of chlorine plus 1.12 tons of caustic.

** assuming 3413 Btu/Kwh

*** a fuel by-product credit of 2.9 million Btu per ton accrues to the process, due to hydrogen generation

EXHIBIT 2812-5

DETAILS OF ENERGY CONSUMPTION*** IN CHLORINE/CAUSTIC PRODUCTION

Operation	Energy Used Per E.C.U.* Electricity (Kwh)	Steam (lbs)
Brine Purification	5	500
Brine Heating		1400
Electrolysis (AC)**	3000	
Chlorine Cooling and Drying	2	
Chlorine Compressing	75	
Liquefaction of 50% of Chlorine	125	
Misc. Gas Evacuating; Ventilation	150	
Caustic Concentration		7500
Totals	3357	9400

* E.C.U. stands for electrochemical unit. One E.C.U. is one ton of chlorine plus 1.12 tons of caustic in 50% solution

** Assuming diaphragm cell operation

*** In addition, an energy credit of 2.9×10^6 Btu/E.C.U. results from hydrogen generation.

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EXHIBIT 2812-6

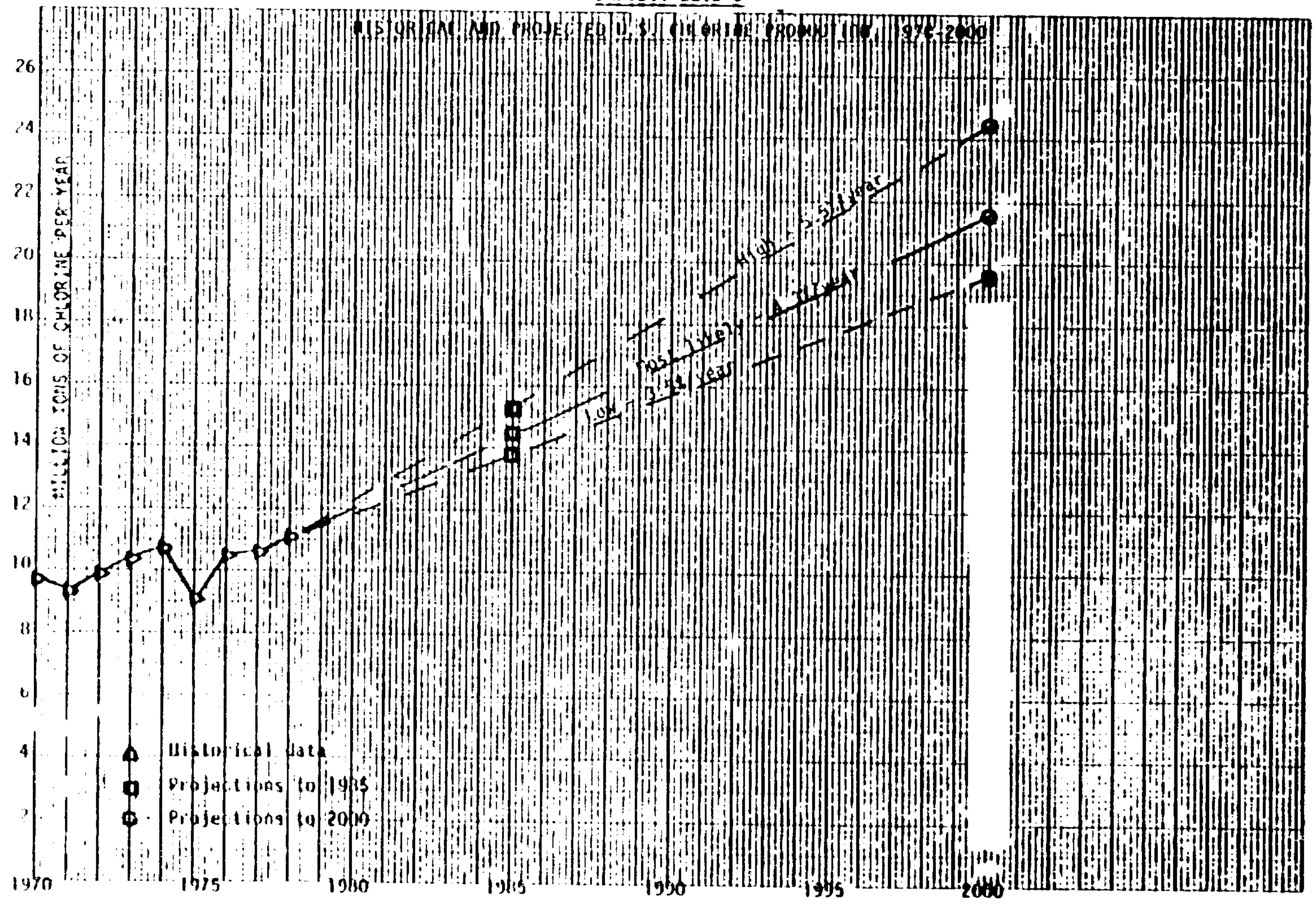

EXHIBIT 2812-7

ESTIMATED ANNUAL ENERGY CONSUMPTION IN CHLORINE-CAUSTIC PRODUCTION FOR SELECTED YEARS

	1975 (1) (Base Year)	1985 (3)	2000 (4)
	(all data in BTU x 10^{12})		
Purchased Fuel	94.2	126	135
Purchased Electricity (2)	34.2	68	85

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(1) From Exhibit 2812-2

(2) Electricity converted to BTUs at 3413 BTU/kWh

(3) Data for 1985 based on the following assumptions:
- a) 95% of production is via diaphragm cells and 5% membrane cells.
- b) diaphragm cell unit energy consumption in 1985 is 13% below levels report in Exhibit 2812-5.
- c) total production of chlorine in 1985 is 14.5 x 10^6 tons, as per Exhibit 2812-6.
- d) use of purchased fuel is 53% for generating steam, 47% for generating electricity.

(4) Data for 2000 based on the following assumptions:
- a) 75% of production is via diaphragm cells and 25% membrane cells.
- b) diaphragm cell unit energy consumption in 2000 is 27% below levels reported in Exhibit 2812-5.
- c) total production of chlorine in 2000 is 21.6 x 10^6 tons, as per Exhibit 2812-6.
- d) use of purchased fuel is as per note 3 (d) above.

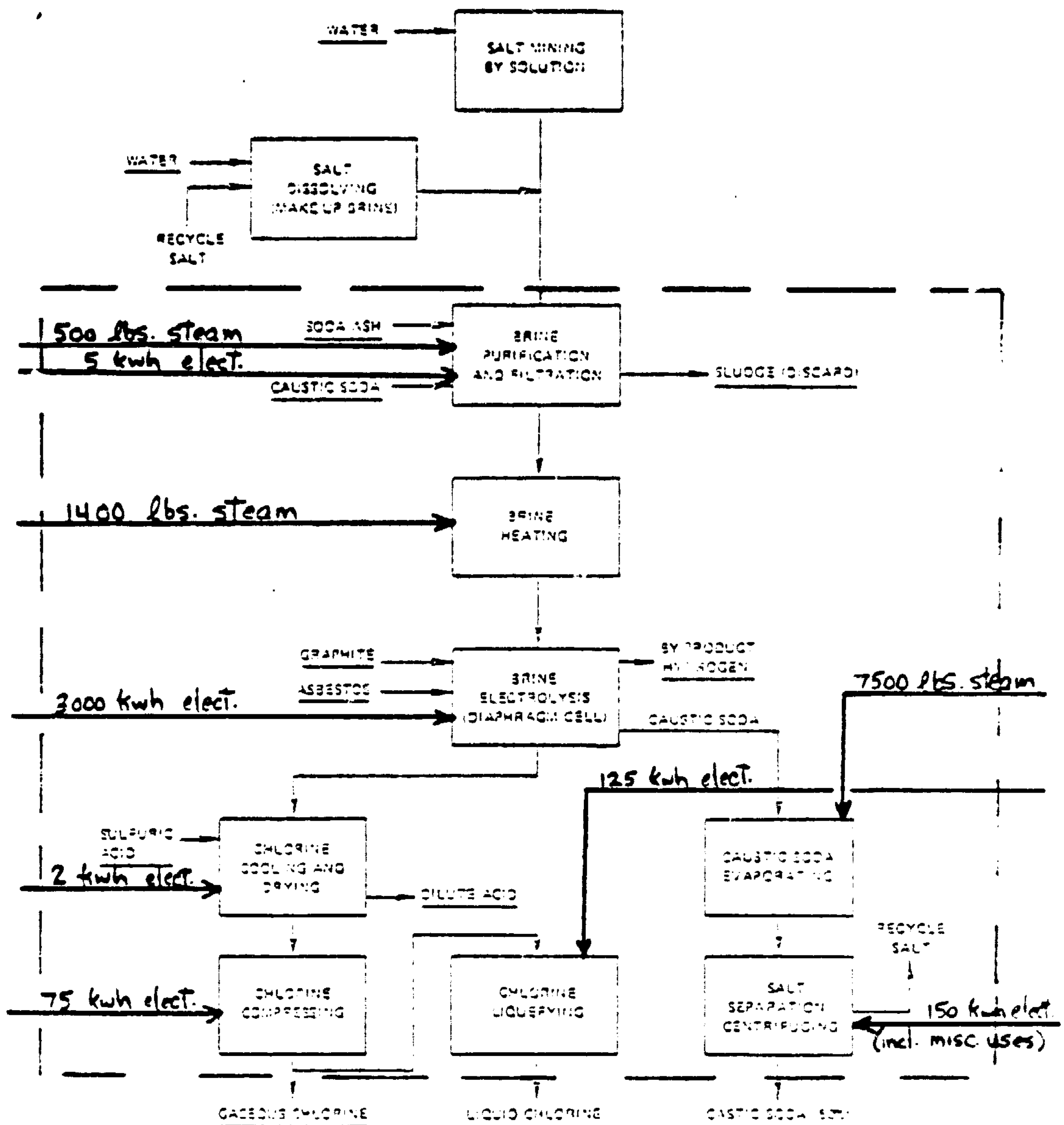
EXHIBIT 2812-8

CHLORINE/CAUSTIC PLANT FACTORS

TYPICAL PLANT CAPACITY TONS/YEAR	PLANT SIZE RANGE TONS/YEAR	ELECTRIC LOAD FACTOR	THERMAL ELECTRICAL COINCIDENCE FACTOR	PROJECTED APPLICABILITY TO 2000, TONS/YR.
150,000	2,000 - 2,000,000	0.95	1.0	365,000

EXHIBIT 2812-9

CHLORINE/CAUSTIC ENERGY FLOW SCHEMATIC*



* All figures based on one E.C.U. of production

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ALUMINA PRODUCTION

1.0 PROCESS IDENTIFICATION

This section identifies and specifically defines the industry, and provides a brief description of the production process currently employed.

1.1 SIC Classification

The production of alumina is classified under SIC code 2819, which covers "establishments primarily engaged in manufacturing industrial inorganic chemicals, not elsewhere classified". This "miscellaneous" category covers nearly two hundred different chemicals, including major inorganic salts, rare earth metal salts, some elemental gases, and some alkali metals. Sulfuric acid, by far the highest volume chemical produced in the U.S., is included in SIC 2819, as well as many other common chemicals.

1.2 Process Description

The production of alumina (Al_2O_3, or aluminum oxide) constitutes the middle link in the sequence of steps used to extract aluminum metal from bauxite ore. At the present time, bauxite is the only raw material used for the production of alumina on a commercial scale in the U.S. The extraction of alumina from bauxite is accomplished using the Bayer process, illustrated by the flow diagram in Exhibit 2819-1.

In the Bayer process, finely ground bauxite ($\sim$ 35 mesh) is digested at elevated temperatures under pressure, using a caustic soda solution as the digestion liquor. The alumina hydrate in the bauxite is chemically

dissolved as sodium aluminate by the caustic (which, incidentally, is commonly produced on-site by reacting soda ash with lime).

Bauxites used in the production of alumina contain alumina trihydrate and alumina monohydrate. The U.S. industry has traditionally been based on Caribbean bauxite which is primarily trihydrate, whereas European industry has been based primarily on monohydrate. Optimum reaction conditions vary with the hydrate type as follows:[1]

Trihydrate: 128-192 g/l NaOH @ 250°-340°F (50-60 psi)

Monohydrate: 257-389 g/l NaOH @ 390°-570°F (up to 500 psi)

The digestion temperature is obtained either by steam-jacketing the reaction units or, more commonly, by direct injection of steam.

After the digestion step, the insoluble components of the bauxite, primarily the oxides of iron, silica and titanium, are removed by thickening and filtration. The separated solids, known as red mud, are discarded; about 0.8 tons of red mud per ton of alumina is typical in U.S. plants.

The resulting main process stream (sodium aluminate solution) is filtered and pumped to precipitators, where it is cooled to 120°-140°F. About half of the alumina is precipated during a 34-36 hour period (digestion, by contrast, takes about one hour), after which it is washed and sent to rotary kilns for calcination.

The kilns, which operate about 2100°F, remove moisture and water of hydration form the alumina. Following calcination, the alumina is suitable for feed to reduction plants.

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(1) EPA Office of R&D, "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options", Vol. VIII: Alumina/Aluminum Industry Report, Dec. 1976, p. 106.

2.0 NATIONAL DATA

The annual national data presented in this section are summarized in Exhibit 2819-2. The derivation and significance of the production and energy consumption data are discussed in the following sub-sections.

2.1 Capacity and Production Data

There are nine alumina plants within U.S. territory (see Exhibit 2819-3). Eight of these are located within the continental U.S. and the ninth is in the Virgin Islands. Six of the alumina plants are located on the Gulf Coast, because of their proximity to imported bauxite and the availability of natural gas. The two plants in Arkansas were originally based on domestic bauxite, but have now turned to foreign sources for part of their supply due to the poor quality of Arkansas bauxite.

With the exception of the plant in St. Croix, which was built in the 1960's, all of the present U.S. alumina plants are relatively old. The oldest plant was built by Alcoa at Mobile, Alabama in 1940; two more (Kaiser at Baton Rouge and Reynolds at Hurricane Creek) were built prior to 1946, and the rest began operation in the late 1940's and early 1950's.

Total U.S. alumina capacity is about 7.8 million short tons annually. As shown in Exhibit 2819-4, plant sizes range from 370,000 tons/yr. to 1,385,000 tons/yr, with a mean size of about 850,000 tons/yr. By modern standards, these plants are considered small. Most new installations being built abroad start at over 1 million and more typically 2 million tons per year.

Since 1.93 tons of alumina are required to produce 1 ton of aluminum,[1] the total alumina requirement of the U.S. aluminum industry, when operating at full capacity, is nearly 10 million tons.[2] This is about 2 million tons more alumina than can be produced domestically. As a result, during periods of strong aluminum demand, the alumina industry operates at virtually 100% capacity factor. In 1974, for example, U.S. alumina production totalled 7.8 millions tons.[3] In 1975 and 1976, when demand for aluminum was relatively weak, alumina production amounted to 5.8 million tons and 6.6 million tons, respectively.[3] Total production capacity in each year, as previously mentioned, amounted to 7.8 million tons annually.

It should also be noted that not all domestically-produced alumina is used for aluminum production. Roughly 10 percent of the alumina is used to make refractories, catalysts and other chemicals. This alumina is primarily non-calcined and therefore requires less energy input than calcined alumina.

2.2 Annual Energy Consumption

Since alumina is only one of hundreds of products included in SIC 2819, the energy consumption data reported by the U.S. Census Bureau[4]

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(1) Gordian Associates, "The Data Base: The Potential for Energy Conservation in Nine Selected Industries", Federal Energy Administration, June 1974, p.302.

(2) Bureau of Mines, "Mineral Commodity Summaries", U.S. Department of the Interior, 1978, p.5.

(3) H.F. Kurtz, Division of Non-Ferrous Metals, U.S. Bureau of Mines (202) 634-1080.

(4) Bureau of Census, "Annual Survey of Manufactures", Fuels and Electric Energy Consumed, 1975 edition.

for SIC 2819 is not representative of the alumina industry. Instead, annual energy consumption in this industry can be estimated as the product of annual output (in tons) and energy consumption per ton. These figures are found in sections 2.1 and 3.1 of this report, and have been used to compile the data presented below for the year 1975 (for consistency with the latest available Census data):

1975 ENERGY CONSUMPTION IN ALUMINA PRODUCTION

	MMBTU/TON	BTU x 10^{12}***
Fuel*	10.20	59.2
Electricity**	0.94	5.5
Total	11.14	64.7

* Includes fuel used for all purposes (i.e. calcination and steam generation).

** Electricity converted to BTU at 3413 BTU/KWH.

*** 1975 production of alumina totalled 5.8 million tons.

3.0 PROCESS ENERGY REQUIREMENTS

This section describes the energy consumed per ton of alumina produced, as well as providing detail on the type of energy required. A summary of the energy requirements per unit output appears in Exhibit 2819-5.

3.1 Unit Energy Consumption Data

Energy consumption in alumina production is largely a function of the type of bauxite being used as raw material. Electric energy consumption, for example, is higher for grinding monohydrate material because of its relative hardness compared to trihydrate. For U.S. plants charging primarily trihydrate bauxite, electric energy consumption has been reported at 160-300 kWh per ton of alumina, based on crushed bauxite.[(1)] With monohydrate bauxite power consumption is as much as 40% greater. Taking into account the fact that U.S. bauxite imports contain about 15% monohydrate, and that about 25% of the bauxite is uncrushed, an average power consumption of 275 kWh per ton of alumina is estimated[(2)].

Fuel is used in the Bayer process to generate steam for bauxite digestion and caustic concentration, and for firing the calcining kilns. Steam consumption has been estimated to vary as follows.[(3)]

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(1) EPA Office of R&D, "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options", Vol. VIII: Alumina/Aluminum Industry Report, Dec. 1976, p.110.

(2) Confirmed by Reference 1 above and by: Gordian Associates, "The Data Base: The Potential for Energy Conservation in Nine Selected Industries", FEA, June 1974, p.300.

(3) EPA Office of R&D, op.cit.

Trihydrate - 3000-8000 lb steam/ton alumina

Monohydrate - 4500-14,000 lb steam/ton alumina

In each case, the lower figure corresponds to large modern installations. Since U.S. installations are generally neither large nor modern, and allowing for an input of roughly 15% monohydrate bauxite, an average steam consumption of 6,000 pounds per ton of alumina was estimated.

Most of the major alumina producers have their own limestone quarries because a high grade of lime, and thus limestone, is required to avoid introduction of impurities into the system. The lime calcination is generally carried out at the plant and therefore is an energy requirement of the process.

Since limestone requirements range from 0.09-0.18 ton per ton of alumina and the heat requirements for calcination are 2.36×10^6 Btu per ton of limestone, the thermal energy requirements for lime calcination range from $0.21-0.43 \times 10^6$ Btu per ton of alumina.[(1)] An average value of 0.32 MMBTU per ton of alumina is assumed herein.

There is also a fuel requirement for the calcination of alumina, which, for rotary kilns, has been estimated to vary between 2.7-5.0 MMBTU per ton of alumina[(2)] depending on the size and efficiency of the kiln. The average in U.S. Bayer plants is around 3.9 MMBTU of fuel per ton of alumina.

The fuel used for calcining and for steam generation is typically gas. For steam generated at 300 psig (for digestion) with a boiler

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(1) Ibid

(2) Ibid, p.111

efficiency of 80%, the fuel usage for steam generation is about 6.0 MMBTU per ton of alumina. The total gaseous fuel used is thus 6.0 plus 0.32 plus 3.9, or 10.2 million BTU per ton of alumina.

3.2 Details of Electricity Consumption

The power consumption in Bayer plants is mainly for grinding the bauxite, with lesser quantities used for grinding lime and for driving mixers, rotary kilns, pumps, etc. As illustrated in section 3.1, power consumption is largely a function of the hardness of the bauxite used.

Alumina plants operate continuously, 24 hours a day, generally with annual load factors in the region of 90 percent (except where modified by local market factors). There does exist the possibility for modifying the plant daily load curves by scheduling grinding operations to off-peak hours, assuming adequate storage is available for the materials. In general, however, it may be considered that the production of alumina requires a steady, reliable source of electric power on a 24-hour per day basis.

3.3 Details of Thermal Energy Consumption

As explained in section 3.1, fuel is used mainly for steam generation for digestion and caustic concentration, and also for firing the calcining kilns. With regard to digestion, steam is required at 300 psig and steam credits accrue at various pressures due to flash tanks. This steam is then utilized in spent liquor recovery and lime calcination (for evaporation and preheating), and for preheating caustic. An approximate

breakdown of the quantity and uses of the steam credits appears in Exhibit 2819-6.

As previously explained, optimum digestion conditions vary with the hydrate type, monohydrate requiring more caustic at higher temperatures and pressures than trihydrate. With the U.S. utilizing about 15% monohydrate bauxite, common reaction conditions are about 400°F and 200 psig in U.S. Bayer plants.

The kilns, which are gas-fired, operate at about 2100°F. In addition to the heat rejected in alumina rotary kilns through radiation (200 BTU/lb of alumina) and through alumina sensible heat loss (250 BTU/lb of alumina at 1100°F), there is a sizable heat loss in the stack gases amounting to 700 BTU/lb of alumina at 800°F.[1]

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(1) Dow Chemical Co., "Energy Consumption: The Primary Metals and Petroleum Industries", prepared for U.S. EPA, published by NTIS, April, 1975, p.28.

4.0 ANTICIPATED TRENDS

This section discusses the trends which are likely to occur in the industry through the year 2000. The major emphasis is on three areas: marketing, process technology, and energy consumption.

4.1 Product Growth Trends

Since about 90% of all alumina produced is consumed in making primary aluminum, its future demand will be predicated on the growth of the primary aluminum industry. Exhibit 2819-7 summarizes the U.S. Bureau of Mines forecast of U.S. and rest-of-world aluminum demand through the year 2000. As shown in this Exhibit, U.S. demand for primary aluminum metal is expected to increase by an average of 4.6% per year through the year 2000, with most probable demands reaching 9.8 million tons in 1985 and 18.8 million tons in 2000.

These demand levels imply the following demand levels for alumina, based on 1.93 tons of alumina required per ton of aluminum, and assuming that aluminum production accounts for 90% of alumina demands:

PROJECTED ALUMINA DEMAND LEVELS FOR U.S.

(million tons)

	For Aluminum Production	For Other Uses	Total
1985	18.9	2.1	21.0
2000	36.3	4.0	40.3

Note: 1975 alumina production, for reference, totalled 5.8 million tons.

Regarding actual production levels for alumina, three factors are of major importance in assessing the future U.S. situation:

a) The depletion of bauxite reserves;

b) The development of new processes for producing alumina from materials other than bauxite;

c) The price of bauxite

a) The Depletion of Bauxite Reserves

Aluminum is the most plentiful and widely-spread metal in the earth's crust, and is present in many varieties of rock, the best known being bauxite. The following table estimates bauxite reserves in the Western world:(1)

	Million Tons	
Africa	8400	
Guinea		6100
Cameroon		1200
Australia	6100	
America	3600	
Brazil		1000
Jamaica		1000
Surinam		800
Europe	900	
Asia	1100	
TOTAL	20,100	

Considering the above reserves and projected requirements, there is no indication that there will be a shortage of bauxite in the next half century. It should be borne in mind, however, that demand is a function of price. The impact of anticipated trends in bauxite prices is discussed below.

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(1) OECD, "Industrial Adaptation in the Primary Aluminum Industry", Paris, 1976, p.24.

b) Development of Non-Bauxite Raw Materials

Whereas the major part of rich bauxite deposits lies in tropical areas, the "other" ores (mainly silicate ores) are very plentiful in the temperate areas such as the United States and Europe. In the U.S., substantial effort has been devoted to developing a commercially viable process for treating domestic low-grade aluminum resources because of the heavy dependence on foreign bauxite. At the present time, no less than twenty processes for producing alumina form clay and anorthosite are at various stages of development within the U.S. However, as discussed in depth in the following sections, none of these processes is close to being competitive with the Bayer process, despite the large effort and heavy funding.

c) The Price of Bauxite

As mentioned above, the price of bauxite is a critical factor in the future development of the alumina and aluminum industries. Compared with other materials, aluminum has historically been able to develop partly because of its technical advantages but also because of the steady improvement in the competitiveness of aluminum prices, which have been maintained partly because the rate of increase in its cost components has remained lower than for competing materials. This situation is presently in a state of flux. In Jamaica, for example, the government in Spring, 1974 altered the system of levies charged on bauxite as a means of increasing revenues. Before the alteration, Jamaican bauxite sold for:

Mining:	\$5.4 per metric ton
Levies and Taxes:	\$2.6 per metric ton
	\$8.0 per metric ton

In the new system, the item "levies and taxes" is replaced by a fixed levy of \$0.5 per metric ton plus a percentage of the ingot ultimate selling price (converted to percent of metal contained in the bauxite), amounting to 7.5% in 1974/1975, 8% in 1975/1976 and 8.5% in 1976/1977[1]. At the present time, for example with ingot listing at 57 cents per pound,[2] the

(1) OECD, "Industrial Adaptation in the Primary Aluminum Industry" Paris, 1976, p.36.

(2) Gampetro, Tony, "Kaiser Aluminum Lifting Ingot Price", Journal of Commerce, May 9, 1978, p.1.

levy amounts to $26.71 per metric ton. Added to mining costs of about $9 per ton, the total bauxite price amounts to over $35 per metric ton. Despite this large increase in the past few years, however, "there is unlikely to be any significant change away from bauxite for the production of aluminum, at least in the medium term."(1)

Thus, it appears that the Bayer process will remain the dominant method for producing alumina for quite some time. This is significant in light of two facts:

(1) U.S. Bayer plants are generally old and small

(2) Most new Bayer capacity is being added at the bauxite mine site due to considerable pressure from both economic and political factors.

The indication here is that few, if any, new Bayer plants will be constructed in the U.S. through 2000, and expansions to existing facilities will come at a very slow rate. The U.S. Bureau of Mines, noting that domestic alumina production increased at an average annual rate of about 3 percent from 1964-1974, projects an expansion of about 2 percent per year through 2000.(2) This results in the following projections of alumina production:

PROJECTION OF U.S. ALUMINA PRODUCTION

(Million tons)

1975	5.8
1985	9.7
2000	12.5

(1) OECD, "Industrial Adaptation in the Primary Aluminum Industry", Paris, 1976, p.36.

(2) U.S. Bureau of Mines, "Mineral Facts and Problems", U.S. Government Printing Office, 1976, p.64.

4.2 Process Changes

As previously mentioned, increased costs of foreign bauxite have increased interest in developing processes to produce alumina from abundant low-grade domestic aluminum resources. The Bureau of Mines, with some funding by industry, is conducting research to test and develop the most promising technologies for recovering alumina from domestic nonbauxitic resources. The Bureau recently estimated capital and operating costs for a number of processes proposed for producing alumina from kaolin and anorthosite clays. Based on the Bureau of Mines' Information Circular 8648, the following two processes appear to have the lowest operating costs and therefore to be the most attractive: (1) the hydrochloric acid leaching, ion exchange process, and (2) the nitric acid-pressure leaching process. These two processes are briefly described below:

a. Hydrochloric Acid Ion Exchange Process

Briefly, in the hydrochloric acid ion exchange process (illustrated in Exhibit 2819-8), clay is dehydrated, leached with hydrochloric acid, and then settled to separate the residue from the aluminum chloride/ iron chloride solution. This solution is then purified with an amine ion exchange system operation to remove the iron chloride, while leaving the aluminum chloride in solution. The aluminum chloride in the solution is crystallized from the solution and decomposed to alumina, with the acid recovered.

Pilot plant work on this process has been carried out by the Anaconda Company in Butte, Montana, and by the Bureau of Mines in Boulder City, Nevada. No commercial plant embodying this process has ever been built and operated.

b. Nitric Acid Ion Exchange Process

The nitric acid ion exchange process consists essentially of eight distinct steps, as illustrated in Exhibit 2819-9, and described below:

1. Calcining the kaolin clay to make the contained alumina selectively available for extraction with nitric acid;

2. Leaching the calcined clay with hot nitric acid at atmospheric pressure to produce a solution of aluminum nitrate and a suspension of the clay-insolubles;

3. Separating the clay-insolubles from the aluminum nitrate liquor in thickeners;

4. Removing the iron and other impurities from the clarified aluminum nitrate liquor by use of a liquid ion-exchange medium;

5. Removing the remaining impurities from the iron-free aluminum nitrate liquor by means of vacuum crystallization of aluminum nitrate monohydrate;

6. Recovering the alumina by hydrolysis of the aluminum nitrate under controlled conditions so that the nitrate values are recovered largely as nitric acid rather than as nitrogen oxides;

7. Recovering the nitric acid and nitrogen oxide values in the form of nitric acid for recycle; and

8. Calcining the product alumina.

Aside from the progress which has been made in developing an alternative to the Bayer process, a great deal of effort has been directed towards improving the basic Bayer technology. The most successful effort has been pioneered by Alcoa, and is known as the Alcoa Fluid Flash Calciner. This flash calciner replaces the conventional kiln used for driving off water of hydration from the alumina product.

In the fluid flash calciner moist alumina is fed into a flash drying section where surface moisture is removed by contact with combustion products and water vapor (see Exhibit 2819-10). The dried hydroxide is held in a fluidized bed dryer, which provides a "thermal fly wheel to allow for feed variations and insure dryness of the hydroxide. Dry hydroxide

is conveyed from the dryer to the calcining section at a controlled rate to maintain constant calcining temperature. Calcined alumina leaving the combustion zone is retained in a fluidization bed for the desired period of time by control of bed level. The combination of calcination temperature and retention time determines the physical characteristics of the product alumina. The calcined alumina is first cooled by direct contact with combustion air in a series of cyclone heat exchangers and finally in a two-deck fluid bed cooler. A tubular heat exchanger in the upper deck heats air for the fluid dryer, and water-cooled tube bundles provide the final cooling in the lower deck.

Fuel requirement for the Alcoa calciner is reportedly about 2.8 MMBTU per ton of alumina, which is about 28% less than the average 3.9 MMBTU/ton cited in section 3.1 as typical for conventional calcining kilns. Power consumption is about 20 kWh/ton, compared to roughly 25 kWh/ton in conventional kilns.

At the present time, the flash calcination process is operating at all Alcoa refineries around the world.[1] It is also being offered for license to other producers, although none have yet purchased the technology.

4.3 Implementation of New Technology

Despite the significant effort being made to develop a commercially viable alternative to the Bayer process, the data presented in section

(1) "Hearings Before the Committee on Commerce, United States Senate, 93rd Congress, Second Session on Energy Waste and Energy Efficiency in Industrial and Commerical Activities", statement of Allen C. Sheldon, Director of Energy Resources, Alcoa, 1974.

4.1 clearly illustrate that none of the candidate processes are even close to being competitive with the conventional process. It is fairly certain that the Bayer process will remain the dominant alumina-producing method through the year 2000.

With regard to improvements in basic Bayer technology, the Alcoa flash calciner is certainly a promising development which offers substantial energy savings over conventional calcining kilns. Alcoa, which accounts for 35% of domestic alumina capacity (see Exhibit 2819-4) has already installed the new design in its plants. Because of the reportedly low capital investment required, it is likely that other producers will, in time, follow suit. For the purposes of this study, we have assumed that 50% of U.S. alumina capacity will utilize the Alcoa flash calciners by 1985, and .4% in 2000.

4.4 Trends in Energy Requirements

The unit energy requirements for the initial stage of the Bayer process, i.e. the ore grinding and digestion, are not likely to change significantly as a result of two competing factors. While it is true that improved housekeeping measures may reduce energy consumption somewhat, the increasing quantities of monohydrate ore being processed will tend to increase energy usage. Therefore, the net result through the end of the century is likely to be no change in energy requirements per ton for grinding and ore digestion. These are presently about 250 kWh of electricity and about 6,000 pounds of 300 psig. steam per ton of alumina. In addition, a small quantity (about 0.32 MMBTU per ton of alumina) of fuel is required for lime calcining.

With regard to the second stage of the process, i.e. calcining, it has been shown that flash calcining is likely to alter the energy needs substantially. Whereas conventional kilns consume an average of 3.9 MMBTU of fuel and 35 kWh per ton of alumina, the flash calciners consume about 2.8 MMBTU and 20 kWH per ton. Based on these data, the estimates of market penetration provided in section 4.3, and the estimates of production provided in section 4.1, Exhibit 2819-11 projects the annual energy needs for alumina production in 1985 and 2000.

As stated in section 3.1, the fuel used for calcining and for steam generation is typically gas at present. Because of the growing natural gas shortage and restrictions on the use of gas, it is likely that producers continuing to raise steam with gas will install cogeneration equipment where it is cost effective to do so. This latter option may be exercised by as much as a third of the industry by the early 1990's, as some producers have already installed such cogeneration facilities. A recent study,[1] citing industry interviews, suggested that gas will largely be replaced by oil for both steam generation and calcining. Based on this, it is reasonable to assume that the remaining two-thirds of the industry will switch to oil. It must be pointed out, of course, that this is simply a rough estimate of the future fuel breakdown. The actual breakdown of fuels will be highly sensitive to a number of factors, including fuel prices and availability, government legislation regarding user taxes and incentives, and the suitability of oil for use in calcining.

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(1) John G. Myers, et.al, "Energy Consumption in Manufacturing", Ballinger Publishing Co., Cambridge, Mass., 1974, p.549.

5.0 PLANT SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements including indications of load profiles, state conditions and reliability considerations. Several plant factors are summarized in Exhibit 2819-12.

5.1 Load Profiles

Alumina production operations are generally carried out on a continuous basis, 24 hours per day and seven days per week. It is, however, feasible to consider shifting a portion of the process (e.g. bauxite grinding) to primarily off-peak hours in cases where equipment capacity, storage capacity and an economic incentive exist. The remaining operations of digestion and calcining do not appear to offer this flexibility.

5.2 Energy Flow Schematics

Exhibit 2819-13 presents a simplified flow diagram of the basic unit operations required in alumina production, with representative quantities of energy input and heat rejection shown. Although the original diagram is from a Dow Chemical Company analysis,[(1)] the numbers have been adjusted to conform with data presented in this report. As shown, there are a number of substantial energy losses emanating from process equipment, including the kiln exhaust gases at 800°F and numerous hot streams at temperatures from 160°F to 1100°F.

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(1) Dow Chemical Compnay, "Energy Consumption: The Primary Metals and Petroleum Industries", prepared for National Environmental Research Center, April, 1975, p.25.

5.3 State Conditions and Mass Flows

The primary use of steam in the Bayer process is for ore digestion, with lesser quantities used for caustic concentration and other small uses. Digestion requires steam at 300 psig, with steam flashed off at various pressures for other uses. The pressures and quantities of flashed steam are shown in Exhibit 2819-6.

Material consumption in alumina production is as follows:(1)

	Range	Average
	(tons/ton alumina)	
Bauxite		2.40
Limestone	0.09-0.18	0.133
Soda Ash	0.05-1.10	0.075
Starch	0.005-0.01	0.006

5.4 Reliability Considerations

Complete power failure in an alumina plant will have a number of damanging effects, including damage to the kiln refractory lining due to uneven heating and cooling when the kiln rotation stops. Any significant brick damage can lead to collapse of the refractory lining, necessitating a plant shutdown for relining.

A partial power failure, or a reduction in power availability, could, in principle be tolerated by load shedding. Ore grinding may be temporarily halted with no adverse effects, provided stored material is available for processing. At worst, a partial power failure should allow the plant to carry out an orderly shutdown with no permanent damage to equipment. The most critical services within a plant are those most closely associated with the kiln, such as kiln rotation and combustion air blowers.

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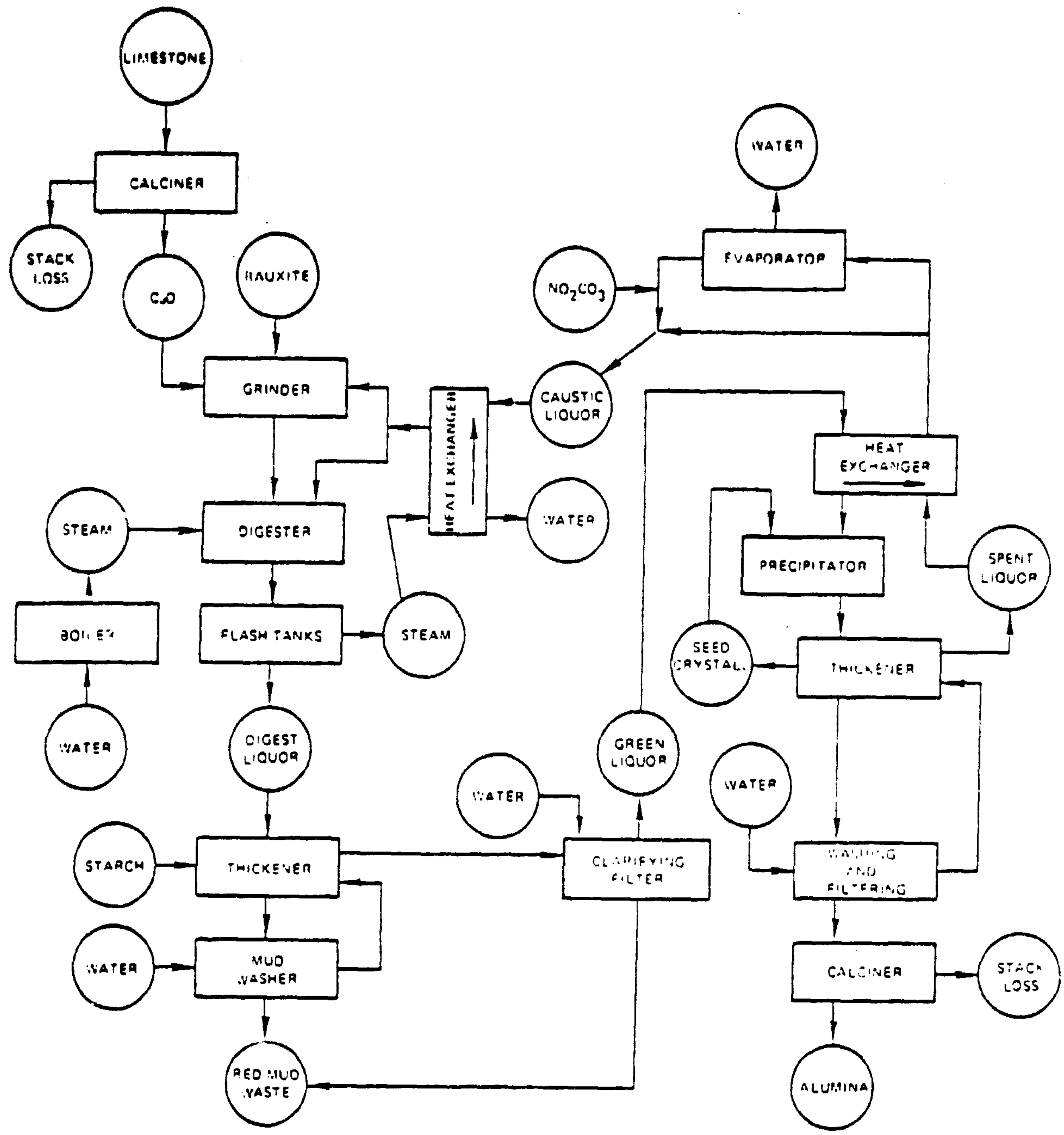
(1) EPA Office of R&D, "Environmental Considerations of Selected Energy-Conserving Manufacturing Process Options", Vol. VIII: Alumina/Aluminum Industry Report, Dec. 1976, p.111.

EXHIBIT 2819-1

BAYER PROCESS FOR PRODUCING ALUMINA



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Source: EPA Office of R&D, "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options", Vol. VIII: Alumina/Aluminum Industry Report, Dec. 1976, p. 107.

EXHIBIT 2819-2

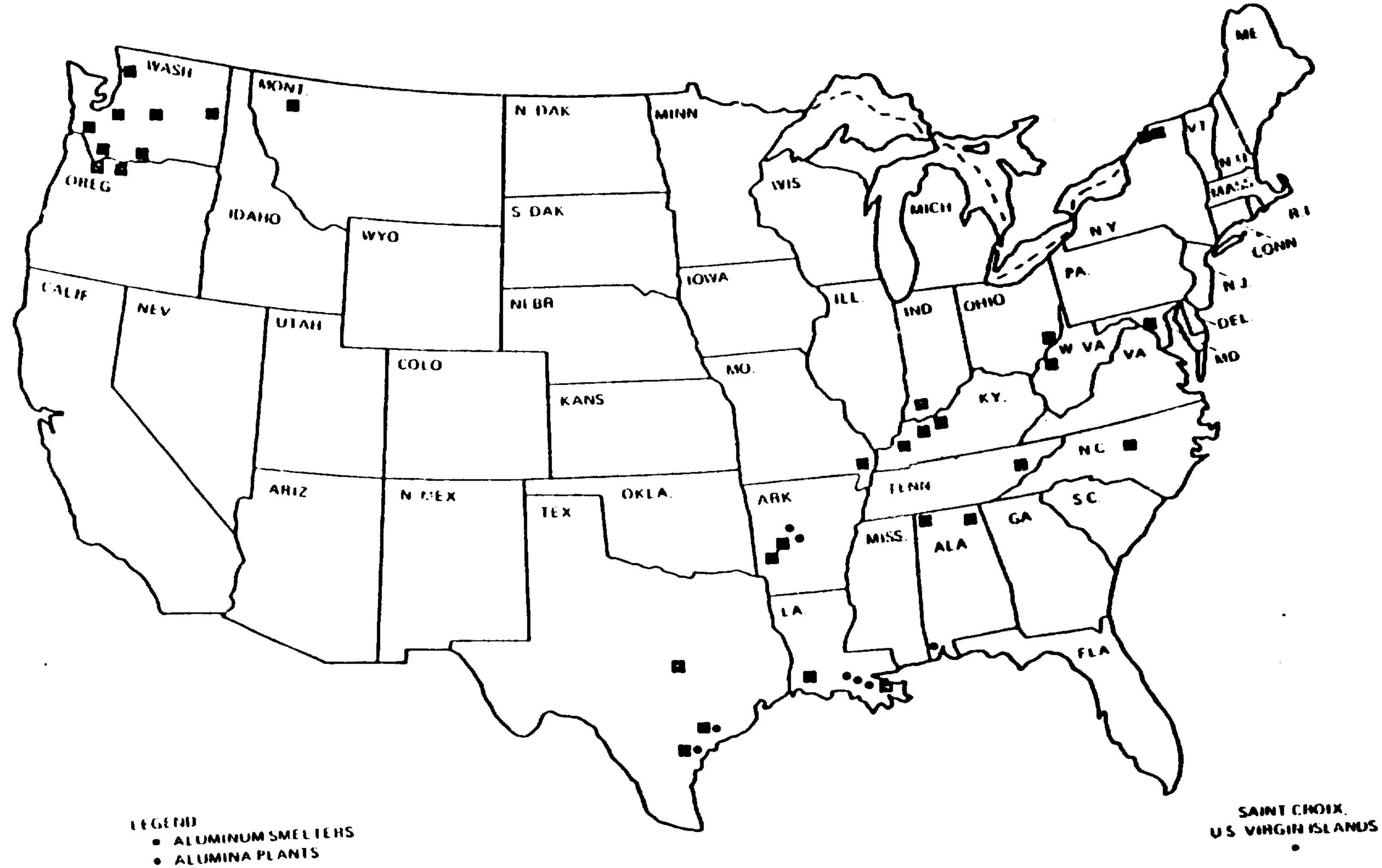
ANNUAL NATIONAL DATA (1975), ALUMINA INDUSTRY

Product Production - Million Tons	Total Energy Consumption Trillion Btu	Purchased Electricity - Trillion Btu	Purchased Fuels Trillion Btu	Coal	Oil	Gas	Other	Total Energy Consumption For SIC Trillion Btu	Percent Total Energy Consumption Represented
5.8	70.5*	5.5*	65.0	--	--	65.0	--	391.2*	18.5

* Purchased electricity converted to Btu at 3413 Btu/kWh

EXHIBIT 2819-3

LOCATION OF ALUMINA PLANTS AND ALUMINUM SMELTERS IN THE UNITED STATES



Source: EPA Office of R&D, "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options", Vol. VIII: Alumina/Aluminum Industry Report, Dec. 1976, p. 91

EXHIBIT 2819-4

U.S. ALUMINA PLANTS
Location and Capacity - 1975

	Short Ton/Yr
Aluminum Company of America	
Mobile, AL	1,025,000
Bauxite, AR	375,000
Point Comfort, TX	1,350,000
Martin Marietta	
St. Croix, VI	370,000
Kaiser Aluminum and Chemical	
Baton Rouge, LA	1,025,000
Gramercy, LA	800,000
Reynolds Metals Company	
Hurricane Creek, AR	840,000
Corpus Christi, TX	1,385,000
Ormet Corporation	
Burnside, LA	600,000
	7,770,000

Source: EPA Office of R&D, "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options", Vol. VIII: Alumina/Aluminum Industry Report, Dec. 1976, p. 92.

EXHIBIT 2819-5

ENERGY CONSUMPTION PER TON IN ALUMINA PRODUCTION

Electricity Million Btu Per Ton	Hot Water Million Btu Per Ton	Steam (Million Btu/Ton)			Direct Fuel Million Btu Per Ton	Exhaust Stream	
		To 300°F	300-500°F	Over 500°F		Temperature $^{\circ}$F	Energy Million Btu Per Ton
0.94*	--	--	4.8	--	4.2	800	1.4

* assuming 3413 Btu/kWh

EXHIBIT 2819-6

STEAM CREDITS IN ALUMINA PRODUCTION

Steam Pressure (psig)	Pounds Steam/Ton Alumina	Disposition
100	1702	evaporation (18%) and preheating
50	1353	preheating
30	736	preheating
15	695	preheating
5	556	preheating

Note: Data based on 6,000 pounds of 300 psig steam consumed per ton of alumina for digestion. Steam credits are from flash tanks.

Source: Peters, F.A., Johnson, P.W., and Kirby, R.C., "A Cost Estimate of the Bayer Process for Producing Alumina", Bureau of Mines, 1966, p. 17.

EXHIBIT 2819-7

FORECASTS OF U.S. AND REST-OF-WORLD ALUMINUM DEMAND, 1973-2000
(Thousand short tons of aluminum metal)

	1973	2000 forecast range: Low	2000 forecast range: High	Probable: 1985	Probable: 2000	Probable average annual growth rate 1973-2000 percent
United States						
Metal						
Primary	5 518	13 800	24 100	9 800	18 800	4.6
Secondary	265	200	2 900	700	2 000	7.8
Nonmetal Primary	724	1 150	2 650	1 300	2 160	4.1
Total primary	6 242	14 950	26 750	11 100	20 960	4.6
Total secondary	265	1 200	2 900	700	2 000	7.8
Total	6 507	16 150	29 650	11 800	22 960	4.8
Cumulative (primary)		270 000	390 000	100 000	340 000	...
Rest of world						
Metal						
Primary	10 121	25 000	48 000	19 700	40 900	5.3
Secondary	486	2 500	5 000	1 300	4 400	8.5
Nonmetal Primary	1 328	1 700	5 000	2 500	4 500	4.6
Total primary	11 449	26 700	53 000	22 200	45 400	5.2
Total secondary	486	2 500	5 000	1 300	4 400	8.5
Total	11 935	29 200	58 000	23 500	49 800	5.4
Cumulative (primary)	...	500,000	750,000	200 000	700 000	...
World						
Metal						
Primary	15 639	38 800	72 100	29 500	59 700	5.1
Secondary	751	3 700	7 900	2 000	6 400	8.3
Nonmetal Primary	2 052	2 850	7 650	3 800	6 560	4.5
Total primary	17 691	41 650	79 750	33 300	66 360	5.0
Total secondary	751	3 700	7 900	2,000	6 400	8.3
Total	18 442	45 350	87 650	35 300	72 760	5.2
Cumulative (primary)		770,000	1 140 000	300 000	1 040 000	

Source: U.S. Bureau of Mines, "Mineral Facts and Problems, 1975 edition", U.S. Govt. Printing Office, 1976, p. 60.

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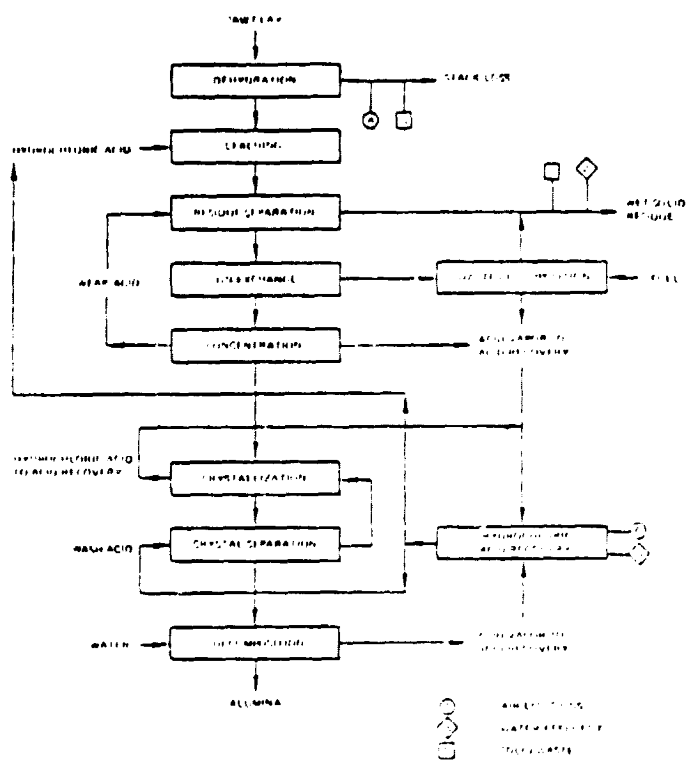
EXHIBIT 2819-8

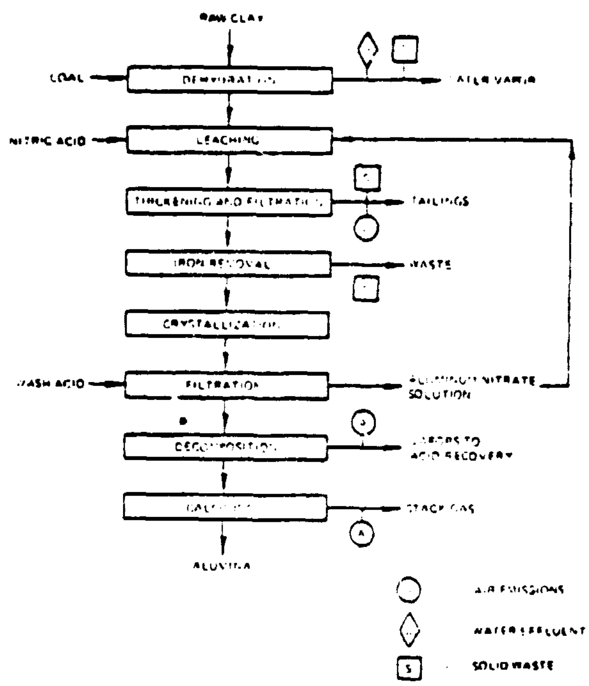
HYDROCHLORIC ACID-ION EXCHANGE PROCESS



Source: EPA Office of R&D, "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options", Vol. VIII: Alumina/Aluminum Industry Report, Dec. 1976, p. 24.

EXHIBIT 2819-9

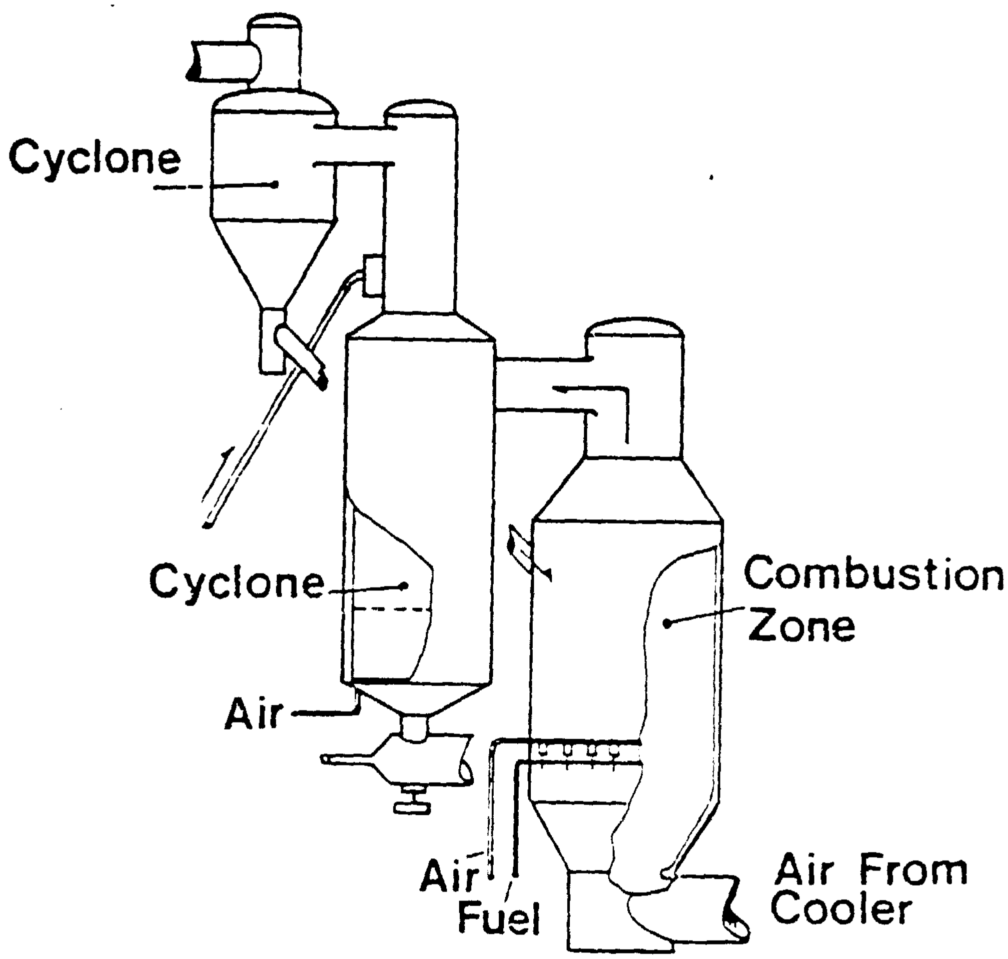
NITRIC ACID-ION EXCHANGE PROCESS



Source: EPA Office of R&D, "Environmental Consider ons of Selected Energy Conserving Manufacturing Process Options", Vol. VIII: Alumina/Aluminum Industry Report, Dec. 1976, p. 24.

EXHIBIT 2819-10

ALCOA FLUID FLASH CALCINER



Source: William M. Fish, Alcoa, "Aluminum Calcination in the Fluid Flash Calciner", paper obtained directly from Alcoa.

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EXHIBIT 2819-11

PROJECTED ENERGY CONSUMPTION FOR ALUMINA PRODUCTION FOR SELECTED YEARS
(all data in trillion Btu)

	Electricity[a]	Steam[d]	Fuel
1975 (Base Year)[b]	5.5	27.8	24.4
1985[c]	8.9	46.8	32.5
2000[c]	11.5	60.3	38.4

(a) Electricity converted to Btu's at 3413 Btu/kWh

(b) Data from Exhibits 2819-2 and 2819-5

(c) Assuming 50% flash calcining in 1985 and 75% flash calcining in 2000

(d) Steam Btu's may be converted to equivalent fuel by dividing by typical boiler efficiency, e.g. 80%.

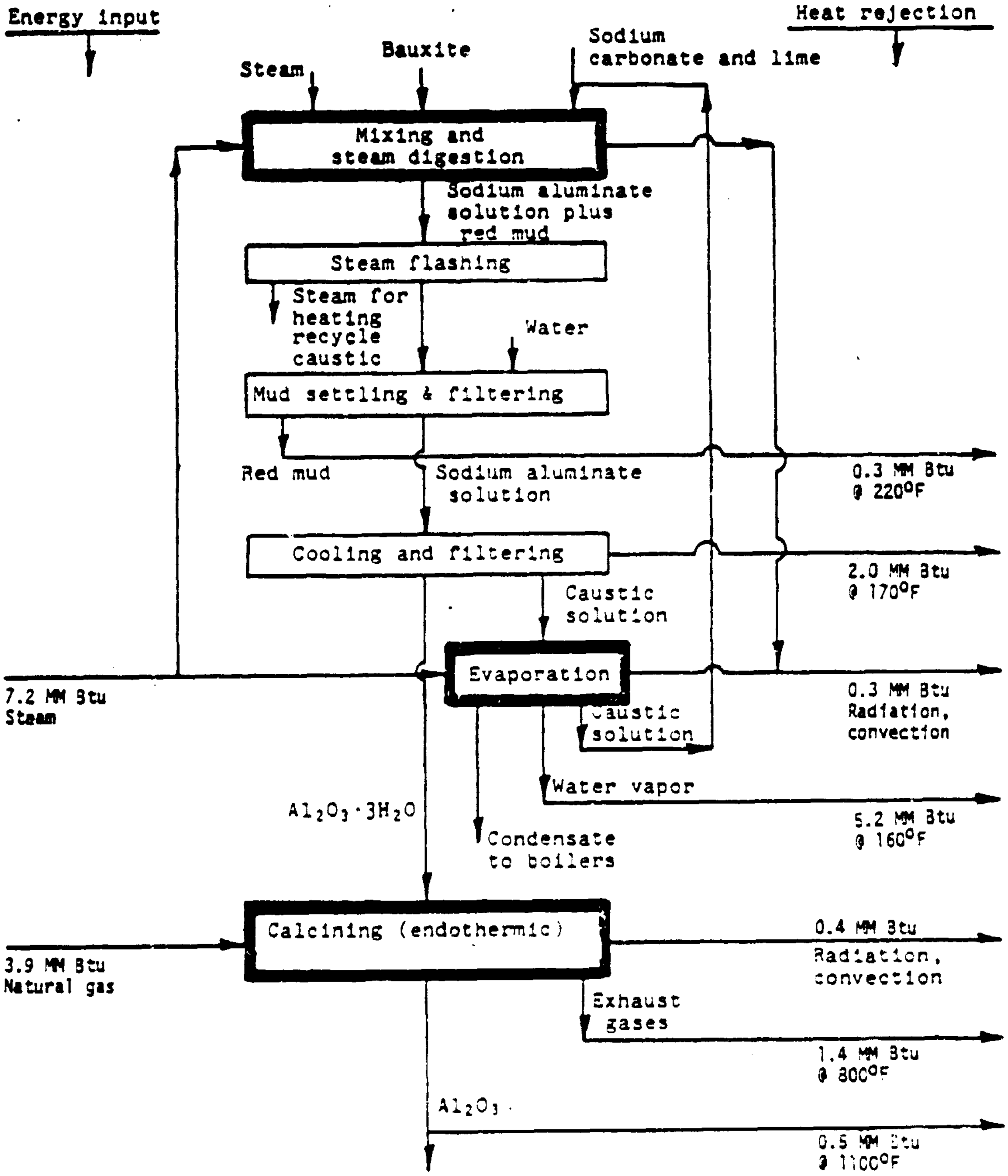
EXHIBIT 2819-12

ALUMINA PLANT FACTORS

TYPICAL PLANT CAPACITY TONS/YEAR	PLANT SIZE RANGE TONS/YEAR	ELECTRIC LOAD FACTOR	THERMAL ELECTRICAL COINDICDENCE FACTOR	PROJECTED APPLICABILITY TO 2000 TONS/YEAR
850,000	370,000 - 1,385,000	0.90	1.0	1,000,000

EXHIBIT 2819-13

ALUMINA PRODUCTION ENERGY FLOW SCHEMATIC
(all data per ton alumina)



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LOW DENSITY POLYETHYLENE (LDPE)

HIGH DENSITY POLYETHYLENE (HDPE)

POLYVINYL CHLORIDE (PVC)

1.0 PROCESS IDENTIFICATION

This section identifies the SIC classification for LDPE, HDPE, and PVC and provides a description of their manufacturing processes.

1.1 SIC Classification

The production of LDPE, HDPE and PVC is classified under SIC code 2821, "Plastics Materials, Synthetic Resins, and Nonvulcanizable Elastomers". Other major products included under SIC 2821 are polystyrene and polypropylene.

1.2 Process Description

- Low Density Polyethylene

Low density polyethylenes are normally produced by the high pressure (15,000 to 50,000 psi) polymerization of ethylene. Polymer density varies between 0.910 to 0.935 g/cc.

The polymerization reaction takes place in four basic steps:

1) Initiation - Chain reaction requires an initiator (or catalyst, although not really a catalyst by definition). Peroxides, AZO compounds, and oxygen are used commercially for initiation. The initiator creates free radicals for the reaction.

2) Propagation - continuous reaction of ethylene with free radicals (created by initiator) to maintain chain reaction.

3) Termination - of free radical groups by combining with other free radical groups to produce polymer chains.

4) Chain transfer - intermolecular, occurs during propagation; intramolecular, used to control or adjust the molecular weight of the polymer. Chain transfer agents are called modifiers and are usually light paraffins (hydrogen or propylene). They act to terminate one polymer chain and start another, and are used in concentrations of several percent in the reactor.

In most processes, two types of reactors are used, tubular and autoclave, with yields of 22-30% conversion per pass and 10-20% conversion per pass, respectively. Process feed consists of high purity ethylene (99.8%+), initiator and a chain transfer agent. Process product and by product are, respectively, low density polyethylene and waxes (low molecular weight polymer). (Approximately 55% of all LDPE produced today is by the tubular process and the remaining 45% is by the autoclave process.[10])

As illustrated in the flow diagram in Exhibit 2821-1, the feed materials are compressed by a primary compressor to approximately 10-20% of the polymerization/reactor pressure, whereupon they are mixed with recycled, ethylene and compressed a second time to polymerization pressure (15,000 to 50,000 psi) and continuously fed to a reactor (tubular or autoclave) where a portion of the ethylene is polymerized. Upon leaving the reactor the ethylene - polyethylene mixture is expanded and enters a primary, high pressure separator and subsequently a secondary, low pressure separator. The ethylene from the separators is cooled, dewaxed and recycled. Polymer from the secondary separator is fed to an extruder and pelletized, cooled, and transported to storage silos.

- <u>High Density Polyethylene</u>

High density polyethylenes are normally produced by low pressure processes (15-3000 psi). Polymer density varies between 0.940-0.960 g/cc.

Three types of processes are employed commercially;

1) Slurry Process
2) Solution Process
3) Gas Phase Process

Organic solvents are used in the slurry and solution processes, in order to dissolve reactants and polymer, reduce the viscosity of the

reaction solution (ethylene, catalyst, solvent, polyethylene), control olefin (ethylene) consumption, and promote heat transfer. In the solution process all the polyethylene dissolves in the solvent, whereas this is not the case in the slurry process. In the gas phase process no solvent is required.

Several types of solid catalysts are used for polymerization. Metallic oxide catalysts derived from transition elements are most common (chromium oxide). Ziegler catalysts and molybdenum oxide are also widely used.

High activity catalysts (5,000-50,000) lb of polyethylene produced per pound of support catalyst have, since 1967, led to the elimination of a polymer/solution filtration step following reaction in order to filter out catalyst.

- Solution Process of the Phillips Petroleum Co.

The Phillips Petroleum Co. solution process is a low pressure process for the continuous production of high density polyethylene from high purity (99%+) ethylene (see process flow diagram Exhibit 2821-2).

Solid catalyst (in a slurry with the hydrocarbon diluent, frequently cyclohexane) is introduced into a stirred, jacketed, autoclave reactor containing high purity ethylene and diluent. Reaction conditions range from 125 to 175°C at 300 to 500 psia. Polymer/diluent is withdrawn from the process and diluent is steam stripped, with a solid polyethylene/water mixture remaining. Diluent is recovered, purified, and recycled to the reactor system. Solid polymer is separated from the water by flotation and then dried. The polymer in powder form is fed to an extruder with selected additives to be sold as pellets.

Ethylene conversion is over 97%. The process produces a full range of polyethylene densities (0.925-0.960 g/cc).

- Particle-Form/Slurry Process of Phillips Petroleum Co.

The Phillips slurry process uses loop reactors (see Exhibit 2821-3) to effect polymerization. Process feed consists of high purity ethylene, high activity catalyst (used in small quantities) and diluent (commonly C_3-C_8 hydrocarbons such as n-hexane, n-pentane), and reaction conditions range from 20 to 100°C at 100 to 500 psia with flow velocities from 10 to 30 ft/sec. Ethylene conversion is over 90%. Product is withdrawn from the loop reactor via settling legs or screw conveyors. The solvent is flashed off at high temperatures and low pressures (usually atmospheric) and recycled back to the reactor feed stream. The solid polyethylene particles are then be processed in auger dryers to remove any remaining solvent. Product may be sold in bulk, granular, or pelletized form.

- Gas Phase Polymerization

In the Union Carbide gas phase process (see process flow diagram, Exhibit 2821-4) gaseous ethylene and catalyst (dry powder form) are fed continuously to a fluidized bed reactor (comonomer, can be added to modify density, and hydrogen to control molecular weight). Reaction pressure is approximately 300 psig, nominal, with temperature controlled between 85-100°C by circulating ethylene through the external cooler. After passing through the reaction zone, the velocity of the gas is reduced in an expanded section to permit disengagement of fine particles (catalyst & polymer). Polyethylene powder is intermittently removed through a gaslock chamber equipped with sequenced valves. An inert gas purge at the base of the product purge tank prevents the mixing of ethylene with the air used in the pneumatic conveying system.

- Polyvinyl Chloride

Vinyl chloride may be polymerized commercially by suspension, emulsion, bulk (or mass) and solvent (or precipitate) polymerization. Suspension polymerization is the most commonly used method in the U.S. today (approximately 86% of the U.S. market; bulk polymerized PVC is approximately 14% of the U.S. market) (11)

- Suspension Polymerization

In this technique the monomer is finely dispersed in water by vaporous agitation, and polymerization is started in the droplets by means of monomer-soluble initiators. The reaction is autocatalytic. (See Exhibit 2821-5 for process flow diagram).

Waterjacketed, agitated batch reactors are used (most of them, in the size range of 2000-6000 gal., are glass-lined to prevent polymer build-up; larger reactors, up to 35,000 gal., are made of highly polished stainless steel). The desired quantity of monomer is measured in a weigh tank and transferred to the reactor containing the proper amount of water. Initiator, suspending agent, and buffer are charged into the reactor via the charge bomb. Agitation is started and the mixture is brought to the reaction temperature of 45-55°C. The reaction is usually carried out to 90% conversion and cooling water is used to remove the heat of polymerization. The mixture is then transferred to the dump tank, where it is stripped of unreacted monomer by the application of vacuum. This monomer is recovered and recycled to the day tank. Several runs are combined in the blend tank to assure a more uniform product. The bulk of water is separated in a centrifuge and discharged and the resin is dried in a stream of hot air in a rotary dryer. The product is separated from the wet air stream in a cyclone separator, from which it is screened and sent to storage.

- Bulk Polymerization

The monomer is polymerized in the presence of free radical initiator only. The resulting polymer is insoluble in the remaining monomer, leading to a heterogeneous reaction medium. The rate of polymerization increases with increasing conversion. This acceleration is caused by the precipitated polymer and can be induced by the addition of preformed polymer. Heterogeneous reactions of this type are difficult to control at higher degrees of conversions, when the mixture is extremely viscous and local overheating is a problem, leading to low molecular weights and broad molecular-weight distributions. These difficulties have recently been overcome in a two-stage process which is shown in a simplified flow diagram, Exhibit 2821-6. Sufficient vinyl chloride for a day's operation is transferred from the storage tank into the day tank. A portion, together with approx 0.015 wt % initiator, is pumped into the prepolymerizer, a vertical, stainless steel-clad vessel, equipped with a flat-blade turbine stirrer and baffles. Here, the monomer is polymerized to a conversion of 7-10% at a temperature of 40-70^{o}C. The considerable heat of reaction, amounting to 22,500 cal/mole, is removed by vaporizing excess monomer, which is then recondensed. The reaction products are polymer beads which serve as seed for continued polymerization in the second step. In the second step, the mixture from the prepolymerizer, together with an equal amount of fresh monomer, are transferred into the autoclave, a horizontal reactor holding approx. 750 ft^3, equipped with slowly rotating agitator blades. Here, the reaction is carried to a conversion of 90%. Beyond approximately 20% conversion, the reaction medium is essentially powdery and the heat of reaction is removed by cooling the autoclave jacket and the agitator shaft, and by a reflux condenser. Reaction time

is 5-9 hr. Unreacted monomer is then removed by a vacuum and recovered by vapor compression and condensation in the recycle condenser. The resin is transferred to the resin receiver by means of an air eductor. Fines are collected in a dust separator and removed through a manhole.

2.0 NATIONAL DATA

The annual national data for LDPE, HDPE, and PVC are presented in this section. A summary of energy consumption and production, consistent with the 1975 Census of Manufactures is shown in Exhibit 2821-7.

2.1 Capacity and Production Data

Summarized below is the total U.S. LDPE, HDPE, and PVC production for 1974 through 1978 (1977 and 1978 are estimated).

PRODUCTION(1)
(Millions of Pounds)

	1974	1975	1976	1977*	1978*
LDPE	5,973	4,768	5,813	6,450	6,900
HDPE	2,837	2,467	3,125	3,700	4,100
PVC	4,850	3,648	4,716	5,300	5,750

* C&EN (12/19/78) estimates

Total U.S. capacity for LDPE, HDPE and PVC is summarized below from data available as of the end of the first quarter of 1977.(2)

CAPACITY
(Millions of Pounds)

	1976	1977	1978
LDPE	7,572	7,804	7,976
Announced Expansions	--	232	172
HDPE	3,971	4,423	4,573
Announced Expansions	--	452	150
PVC	6,514	6,677	6,880
Announced Expansions	--	163	203

Plant capacities for LDPE, HDPE, and PVC range from 150 to 650, 125 to 400, and 50 to 320 MM lbs/yr, respectively with typical plant capacities at 375, 275, and 230 MM lbs/yr. (16)

2.2 Annual Energy Consumption

The U.S. Census Bureau reports energy consumption (by fuel type) for SIC #2821 in 1975.(3)

1975, ANNUAL ENERGY CONSUMPTION, SIC #2821

ENERGY SOURCE	CONSUMPTION (x 10^{12} Btu)
Fuel Oil	24.95
Coal	27.68
Natural Gas	72.39
Other*	13.25
Purchased Fuel (Total)	138.27
Purchased Electricity**(a)	24.87
Purchased Fuels and Electric Energy (Grand Total)	163.14

(a) Purchased electricity converted to Btu at 3413 Btu/Kwh
* "Other" includes "Fuels not specified by kind"(3)
** Self-generated electricity is already included in the individual fuel consumptions above, in order to avoid double counting.

Since LDPE, HDPE and PVC are not the only products in SIC #2821, a more accurate assessment of the annual energy consumption for each product was derived. From available utility consumption data(14) for the many types of processes a typical overall energy requirement (on-site only) per pound of product was derived for each product. For LDPE, HDPE, and PVC, the energy requirements are 3.24 x 10^3 Btu/lb, 3.48 x 10^3 Btu/lb, and 2.82 x 10^3 Btu/lb, respectively, (utility consumption

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data are summarized in section 3.1). Using the calculated unit energy requirement in combination with annual production data, a total energy consumed (onsite only) was calculated. Also, from the available utility consumption data, a typical, overall split between the total fuel and total electric energy use was calculated.[a] In order to estimate the total energy consumed (i.e. including off-sites) off-site energy consumption was taken to be 83% of the total onsite energy consumed[4] (33% for fuel and 50% for electric energy). The off-site energy consumption was added to the already calculated on-site energy consumption to arrive at a total. The total purchased fuels was then distributed across the various types proportionately with 1975 Census of Manufactures data, and the resulting 1975 annual energy consumption for LDPE, HDPE, and PVC is shown below:

1975 ANNUAL ENERGY CONSUMPTION, LDPE, HDPE, & PVC

Energy Source	Consumption (x 10^{12} Btu)			
	LDPE	HDPE	PVC	Total
Fuel Oil	1.86	1.65	2.21	5.72
Coal	2.07	1.84	2.46	6.37
Natural Gas	5.41	4.80	6.43	16.64
Other*	1.00	0.90	1.19	3.09
Purchased Fuel (Total)	10.34	9.19	12.29	31.82
Purchased Electricity	17.93	6.53	6.54	31.00
Purchased Fuel and Electric Energy (Grand Total)	28.27	15.72	18.83	62.82

* "Other" includes "fuels not specified by kind"[3]

(a) Onsite Total Fuel and Total Electric Energy Use Split, in percent, (from Section 3.1).

	Total	Electricity	Fuel
LDPE	100.0	66.0	34.0
HDPE	100.0	26.0	74.0
PVC	100.0	13.5	86.5

3.0 PROCESS ENERGY REQUIREMENTS

The following sub-sections describe the energy requirements, thermal and electrical, per unit of production in LDPE, HDPE and PVC manufacture. A summary of the energy requirements per unit output is presented in Exhibit 2821-8.

3.1 Unit Energy Consumption Data

LDPE, HDPE, and PVC production processes require energy intensive operations using steam and electricity. LDPE, in particular, requires a relatively large amount of electricity for its two-stage compression while HDPE and PVC use relatively large amounts of steam in their separation and drying processes.

Typical process (on-site) utility requirements for the production of 1.0 short ton of product are: [a]

Typical, Process Utility Requirements*	LDPE[5]	HDPE[5][6][7]	PVC[5][8]
Steam (tons)	0.55-0.91	1.82	1.64
Electricity (kWh)	1,150-1,270	1,360	270
Cooling Water (gallons)	35,000-44,000	50,000-59,000	17,000

Basis: 1.0 short ton of Product

* LDPE data: tubular reactor process
HDPE data: Solvay, loop reactor process (similar to Phillips "particle form" process)
PVC data: suspension Polymerization.

(a) As discussed in section 2.2, off-sites typically add an additional 83% to the unit energy consumption.

3.2 Details of Energy Consumption

LDPE, HDPE, and PVC production are continuous processes operating 24 hours/day, all year long, with the exception of a once per year clean-up shutdown. In processes where an autoclave reactor is used, usually more than one reactor is available, so that when one is being cleaned the other is on stream, thus preventing complete process interruptions. Total interruption only occurs in the event of a "decomp", a decomposition of ethylene into carbon, hydrogen, and methane, resulting in an explosive venting through a reactor blow-out disk. At the temperatures and pressures involved, ethylene is thermodynamically unstable, a reactor decomp may result from reactor hot spots, local concentrations of initiator, and improper introduction of ethylene feed. In tubular reactor processes (LDPE), a decomp will halt process operation, on the average, for 8 hours. During this time process line steam jacketing must be maintained to prevent gel formation in the lines. Since more than one process line (tubular reactor process) is common at a plant, a temporary halt in operation of one line is not expected to affect overall energy consumption by much. The plant load profile generally shows little variation from the mean and is estimated to be in excess of 90%.

In LDPE processes, an estimated one-third of the total electrical energy consumption is consumed in the multi-stage compression step[9]. In HDPE and PVC processes, the majority of thermal energy (steam) consumed is consumed by the polymer process drying steps. A detailed breakdown of energy consumption by process operation is not available because of the proprietary nature of these processes.

4.0 ANTICIPATED TRENDS

The section discusses trends through the year 2000. Major emphasis is on market development and trends in process technology and energy consumption.

4.1 Product Growth Trends

LDPE, HDPE, and PVC rank first, fourth and second, respectively, in pounds sold in the 1976 U.S. thermoplastic-resin market, accounting for 24.5%, 13.3%, and 19.7%, respectively, of the total thermoplastics sold.[2] High growth-rate markets are expected to be in automotive uses, blow-molded bottles, building construction applications, engineering (high performance) plastics in metal uses, household appliances, and replacement of metal assemblies.[2]

Demand for LDPE, HDPE, and PVC from 1976 through 1985 and 2000 is estimated below and on Exhibits 2821-9 through 2821-11.

Demand[10]
(Billions of Pounds)

	Historical	Forecast	
	1976	1985	2000*[2]
LDPE	5.25	11.89	28.65 ± 10%
HDPE	2.76	6.51	14.33 ± 10%
PVC	4.36	10.23	24.42 ± 10%

* Demand to 2000 is derived from source (2) production forecast; assuming no severe market shocks (ie. government stimulation, product price abnormally rising or plunging, etc.). Production (supply in the current tight market) should match demand; however, since the economy is not always perfect, historical demand data was compared with historical production data and showed a maximum variance of ± 10% (more frequent was a ± 5% variance).

Process capacity in 1980 for LDPE, HDPE, and PVC (in millions of pounds) is expected to be 8,276, 4,749 and 7,098, respectively. Union Carbide's new low pressure LDPE process (to be discussed in the subsequent section) is expected to add 650 million pounds to the 1980 LDPE capacity by 1982. (Total Union Carbide low pressure LDPE process capacity, in 1982, to equal 950 million lbs., i.e. 300 million lbs. by 1980, 650 million lbs. by 1982).

Estimated capacities to 1980, and 1982 for LDPE, are shown below:[2]

	(mm lbs/yr) Capacity at End of Year	(mm lb/yr) Announced Expansions	Capacity Utilization (%)
LDPE			
1976	7,572	--	76.2
1977	7,804	232	80.0
1978	7,976	172	84.7
1979	7,976	--	91.6
1980	8,276	300	99.1
1982	8,926	650	--
HDPE			
1976	3,971	--	79.2
1977	4,423	452	77.5
1978	4,573	150	81.7
1979	4,749	176	85.8
1980	4,749	--	93.5
PVC			
1976	6,514	--	72.2
1977	6,677	163	76.3
1978	6,880	203	80.3
1979	3,062	182	84.8
1980	7,098	36	91.4

In considering the potential growth of the LDPE, HDPE, and PVC markets many factors need to be weighed. On the negative side, LDPE, HDPE, and PVC will be adversely affected by:

- raw material feedstock dependence on imported oil, resulting in higher prices.

- rising capital cost increasing investment thereby limiting the number of market entries and/or expansions by companies.

- reduced demand due to high inflation.

- environmental and safety regulations increasing nonproductive costs and possibly leading to the banning of certain end uses for plastics.

However, on the positive side, LDPE, HDPE, and PVC offer many favorable attributes:

- extensive variety in properties along with versatile fabrication technology allowing for a wide variety of products to be tailored to demand

- better economy resulting from lower cost per unit volume (or area) due to lower density of polymers versus nonpolymerics.

- lower energy and environmental impact than most nonpolymeric materials

- improving waste recovery methods for scrapped plastics (10,000-20,000 Btu/lb[2])

- favorable long term price stability, as illustrated below [2]

¢/lb	1976	1981	1986
LDPE	29.5	39.0	48.0
HDPE	30.6	41.0	51.0
PVC	25.0	35.0	45.0

- new markets in safety use (plastic coated bottles, automotive dashboards) and motor vehicle weight reduction for improved gas mileage.

4.2 Process Changes and Implementation of New Technology

Many technological changes are occurring in the plastics industry to accommodate the growing market, reduce operating cost and energy consumption, and comply with environmental and safety regulations.

In LDPE, Union Carbide recently announced a new low pressure, gas-phase polymerization process. The new process uses the same equipment

as their gas-phase HDPE process. The key to the new process is a family of proprietary catalysts.

In the process, gaseous ethylene and catalyst are continuously fed to a fluidized bed reactor. Reaction pressure is between 100 to 300 psi, markedly below the 15,000 to 50,000 psi levels of the conventional processes. Reaction temperature is controlled at less than 100°C, significantly less than the common 300°C of high pressure processes. Overall operating energy costs, relative to conventional tubular reactor processes, are reportedly reduced by 75% and capital investment cost is cut by one-half. Steam use is negligible, with electric energy being the primary energy source. Union Carbide plans to build a 300 mm lb/yr plant by 1980 and a 500 mm lb/yr and 150 mm lb/yr plant by 1982 bringing total new process capacity, by 1982, to 950 mm lbs/yr, representing approximately 11% of total U.S. LDPE capacity in 1982.

Aside from the new low-pressure process, tubular reactors are getting larger, raising the capacity of production lines and cutting investment and operating costs. New markets are opening up for LDPE use in wire and cable, and protective packaging as a result of new techniques for producing and cross-linking LDPE foams.

In HDPE, high-activity catalysts have lowered production costs by eliminating catalyst-residue removal steps. In addition, their high polymerization conversion rates also have reduced (and eliminated in some cases) the need for monomer recycle. New plants can produce HDPE and polypropylene interchangeably, enabling producers to meet customer demand with greater latitude. Union Carbide has a gas-phase polymerization HDPE process which is reported to reduce capital costs by 25% and

operating costs by 15%. In this process, steam use is neglible and electric energy is the primary energy source. An estimated 6-12% of all HDPE produced at present is made by this process. New markets are being developed by new techniques for blow and injection molding HDPE and crosslinking HDPE foams.

In PVC, environmental and safety problems, resulting from the residual monomer, were overcome by eliminating the manual cleaning of reactors in order to comply with EPA standards for VCM emissions in air and water. Reactor size is increasing, up to 35,000 gal in the U.S. (60,000 gal. in Europe) as compared with conventional 5000 gal reactors, resulting in economies of scale. In addition, shorter polymerization cycles (30% shorter) are increasing productivity. The bulk polymerization process, which does not use any effluent water, has an ecological advantage and lower production and capital cost than suspension polymerization (since there are no drying steps). All bulk U.S. producers (four) hold licenses from Rhone-Poulenc for this process (approximately 11% of U.S. PVC production is via this process[2]). New markets are also being opened for foamed-PVC pipes for low pressure uses.

4.3 Trends in Energy Requirements

In developing an energy conservation target for the Department of Energy for SIC #28, an energy conservation target of 17.3% by 1980, relative to 1972 energy consumption levels, for SIC #2821 was estimated.(15) For LDPE, HDPE, and PVC production, specific energy conservation targets were estimated at 21.0%, 22.2% and 10.0%, respectively. It was assumed

that such a reduction in energy consumption could be achieved by 1985, relative to 1975, for each product, and that the reduction in energy consumption by 2000 would be twice as much as that to 1985, for each product.

In addition, the new Union Carbide low pressure gas-phase polymerization process, which is 75% less energy consumptive (steam use is negligible) than conventional processes, is estimated to account for 10% and 20% of all U.S. LDPE production in 1985 and 2000, respectively.

Distributing purchased fuel and purchased electricity data proportionately from 1975 data proportions (with the exception of LDPE for which the new Union Carbide process was also considered), a summary of the forecast energy consumption for LDPE, HDPE, and PVC production is presented in the following table:

Energy Consumption Trends, 1975-1985-2000

LDPE, HDPE, and PVC Production

($\times 10^{12}$ Btu)	Purchased Fuels	Purchased Electricity	Total Purchased Fuels and Electricity
LDPE			
1975	10.34	17.93	28.27
1985	17.16	35.00	52.16
2000	13.87	33.47	47.34
HDPE			
1975	9.19	6.53	15.72
1985	18.87	13.38	32.25
2000	29.68	21.06	50.74
PVC			
1975	12.29	6.54	18.83
1985	31.03	16.49	47.52
2000	65.83	34.98	100.81
TOTAL (LDPE, HDPE & PVC)			
1975	31.82	31.00	62.82
1985	67.06	64.87	131.93
2000	109.38	89.51	198.89

5.0 PLANT SPECIFIC DATA

This section provides available data relating to specific plant energy requirements, load profiles, state conditions and reliability considerations. Several plant factors are summarized in Exhibit 2821-12.

5.1 Load Profiles

LDPE, HDPE and PVC processes are continuous, operating 24 hours/day, 7 days/week, often with more than one process line in operation. Hence, load profiles generally show little variation and load factors are typically in excess of 90%. Likewise, since operation is continuous, thermal electrical coincidence factors are estimated to be in the range of 0.90 to 1.0.

5.2 Energy Flow, Mass Flow and State Conditions

As noted in Section 3.2, a detailed breakdown of energy consumption by unit operation was not available for proprietary reasons. However it is estimated that approximately one-third of the total electrical energy consumed, in the LDPE process, is consumed in the multi-stage compression step. A conventional high pressure process (LDPE), for 250 million-lb/year capacity, is estimated to require an 11,000-hp pump fed by 2000-hp pumps. The new Union Carbide low pressure LDPE process is estimated to require only a single pump, approximately 2000 hp. For the HDPE and PVC processes, it is estimated that most of the steam is consumed in the process drying steps.

In section 3.1, typical process utility requirements are shown (steam, electricity, and cooling water, per unit output) and illustrated in Exhibit 2821-8 is the energy consumption (Btu) per unit output (tons) showing almost all of the steam utilized in the 300-500^{o}F range.

A summary of typical process reactor conditions and process yields is shown in the following table:

	Type	Typical Reactor Conditions: Temperature (°C)	Pressure (psia)	% Conversion Per Pass	Process Yield
LDPE (0.91-0.935 g/cc)	Tubular	150-300	15,000-50,000	22-30	--
	Autoclave	150-300	15,000-50,000	10-20	--
	*Gas-Phase	>100°C	100-300	na	na
HDPE (0.940-0.960 g/cc)	**Autoclave	125-270	15-3000	--	>97
	***Loop	60-90	350-500	>90	>90
	Gas-Phase	85-100	300	2	99
PVC	**Autoclave, Suspension Process	45-55	90-130	>90	>90
	****Bulk Process, Prepolymerizer	40-70	70-100	7-12	--
	and Autoclave	--	--	>90	>90

* Union Carbide's new LDPE process

** Includes solution process of Phillips Petroleum Co. (300-450 psia and 125-175oC), E.I. DuPont (800-3000 psia and 180-270°C) and others

*** Solway Loop reactor process

**** Bulk polymerization PVC process is a two step process involving a first step polymerization in a "prepolymerizer" and a second step polymerization in an autoclave.

5.3 Reliability Considerations

LDPE, HDPE and PVC, all require the use of electricity, steam, and cooling water in their production. Electricity is used for driving pumps, compressors, extruders, and most other mechanical and electrical functions; steam for drying, heating, jacketing, tempering cooling water, agitating, drawing vacuum (created through venturi jets) and most other thermal functions; and cooling water mainly for controlling reactor jacket temperature and other heat exchanging equipment.

In the event of a power failure, physical damage (as distinguished from the inherent economical damage) could potentially occur in two ways: polymer cooling, hardening, and sticking to reactor walls and other process equipment, and/or a reactor "decomp" (see Section 3.2) or runaway reaction.

The former is a direct result of the loss of steam jacketing (and any other heating) for process equipment such as pipes, valves, separators, extruders, dryers, etc. Clean-up of hardened polymer, in such a situation, would take several days of downtime (labor, mechanical maintenance, parts replacement, etc.) and many hours of run time before acceptable product could be made. In the case of a temporary power failure, less than 8 hours, the resulting damage may not be nearly as severe depending on the process.

A decomp, or runaway reaction, is the direct result of the loss of cooling water to the reactor jacket. Most cooling water systems use water at temperatures much lower than municipal water systems could provide (in the warmer seasons). Cooling water is almost always pumped, for metered flow, and usually refrigerated and filtered. An electrical

power failure would stop pump and refrigeration action. For PVC, the exothermic polymerization reaction, uncontrolled, without a cooling jacket would runaway (a 10°C increase with every doubling of reaction rate). The resulting high temperature would vaporize the already high vapor pressure vinyl chloride monomer thereby causing an increase in pressure, resulting in an explosive venting, probably through a blow-out disk. Exposure to the atmosphere would facilitate polymer hardening (gel formation), present a fire hazard (if not properly vented) and an environmental hazard (especially VCM). A decomp or runaway reaction, without a power failure, results in approximately 8 hours of downtime; with a complete power failure, downtime can increase to several days.

In the case of a power failure in the high pressure LDPE process, a decomp or runaway reaction is unlikely (assuming proper system design). Since compression will also be lost (in addition to cooling water), decomposition and reaction pressure cannot be maintained and hence, the reaction will stop.

In the low pressure LDPE and HDPE gas-phase processes, polymer hardening and decomps are not a problem. Polymer is formed in dry granules and the gas phase does not provide a medium for a decomp.

In the bulk polymerization for PVC, polymer hardening and the probability of a decomp is relatively less than in other PVC processes. Polymerization conversion beyond 20% in the autoclave reactor, yields an essentially powdery reaction medium; reactor pressure is equal to the vapor pressure of the vaporized, unreacted VCM. Since the reaction proceeds to approximately 90% conversion, little VCM is expected to remain, exerting little pressure. Reaction heat is removed however, by

cooling the autoclave jacket and agitator shaft, and by a reflux condenser, to prevent granular polymer from sticking together. Polymer hardening and sticking to reactor walls is possible in bulk polymerization but not to the extent in other PVC processes, in the event of a power failure.

EXHIBIT 2821-1

Low Density Polyethylene - Process Flow Diagram

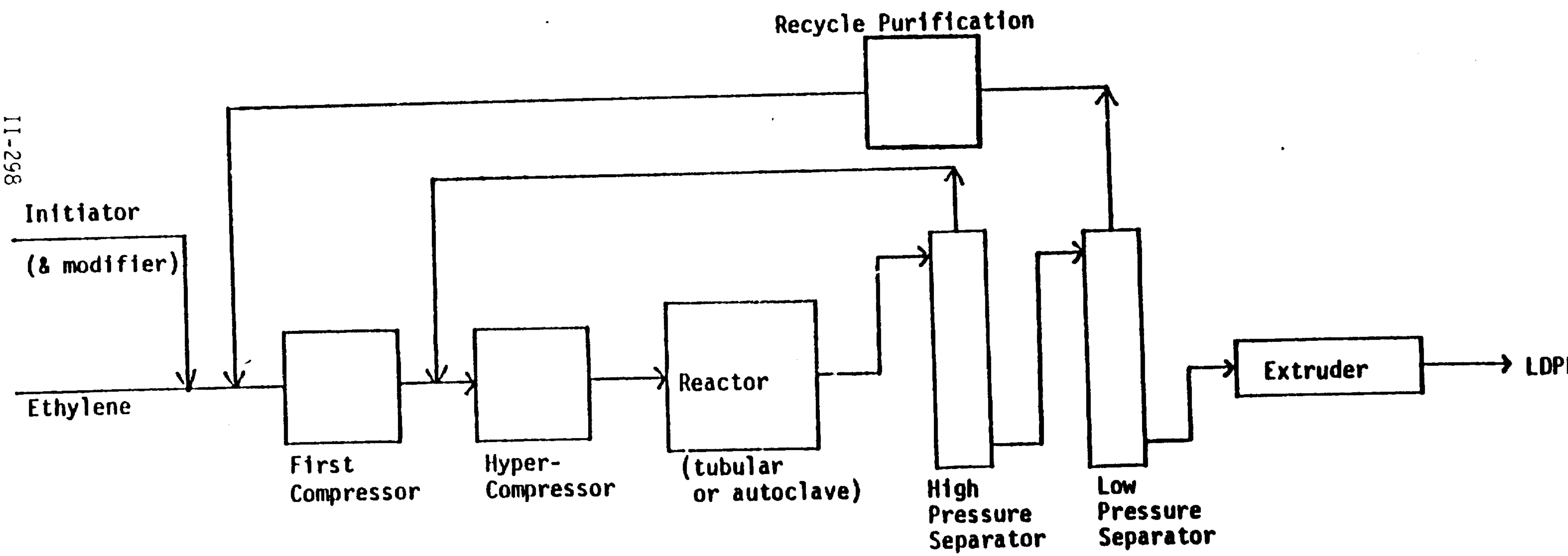


EXHIBIT 2821-2

High Density Polyethylene - Process Flow Diagram

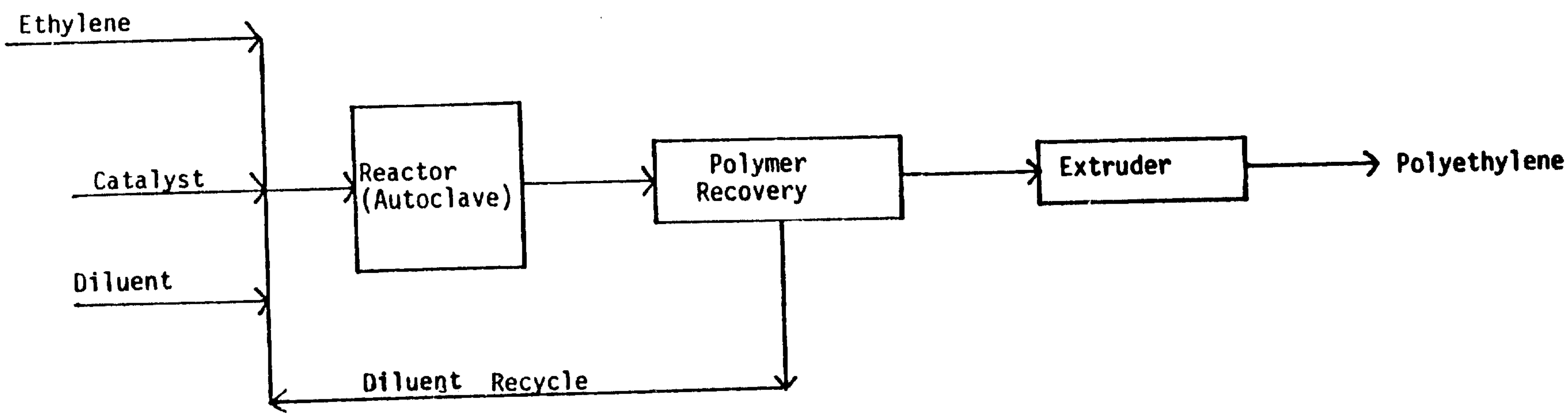
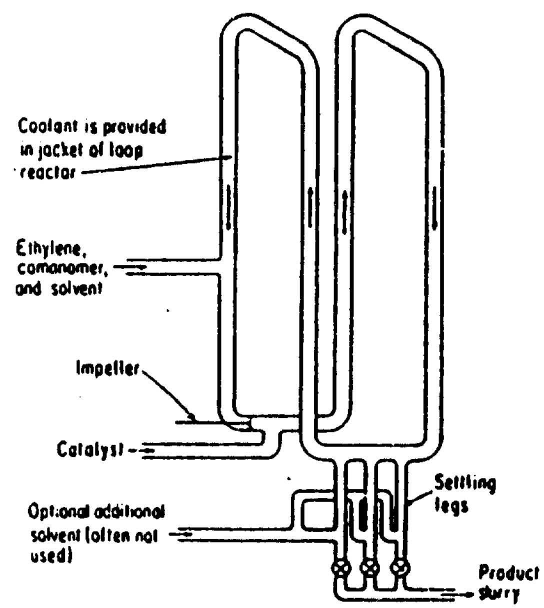


EXHIBIT 2821-3

LOOP REACTOR



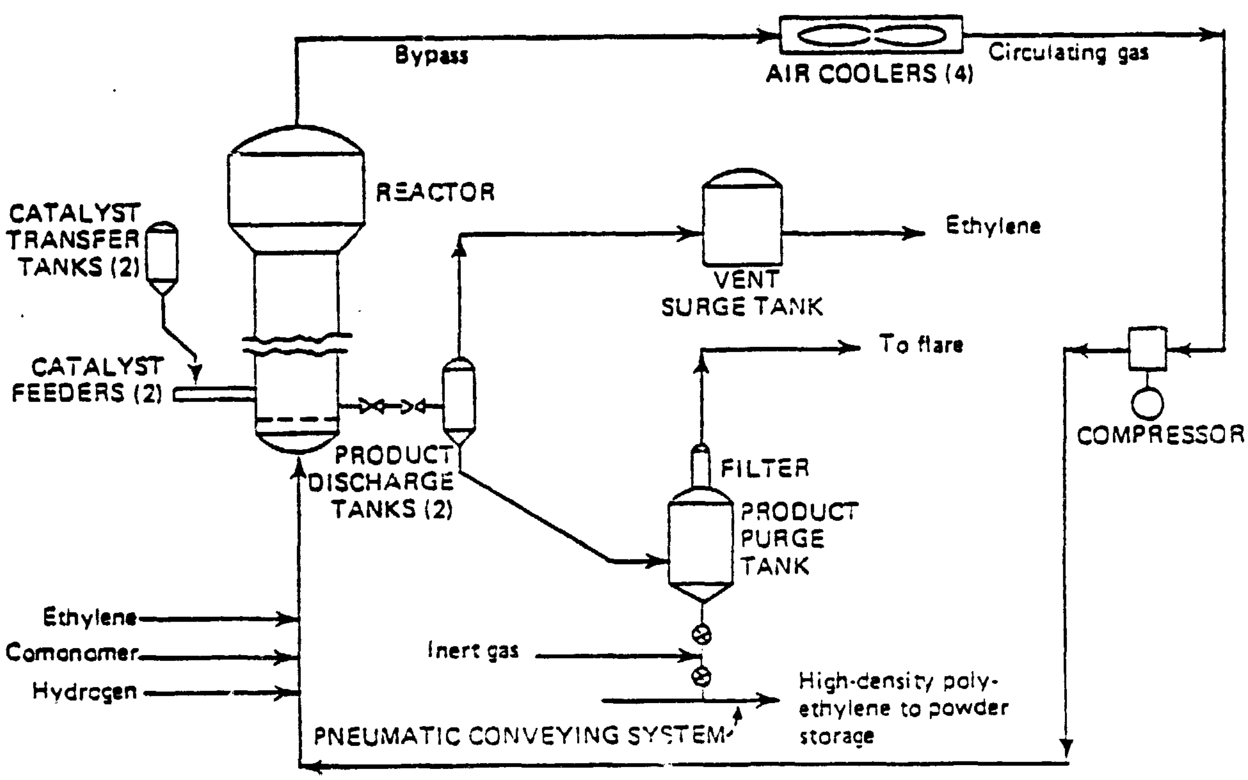
Double Loop,
Tube Diameter: 12-20 inches
Height/Section: ~50 feet
(equivalent length:
280-300 feet)

SOURCE: Albright, Lyle F., Processes for Major Addition Type Plastics and Their Monomers, McGraw-Hill, New York, 1974

EXHIBIT 2821-4

UNION CARBIDE HIGH-DENSITY

POLYETHYLENE PROCESS

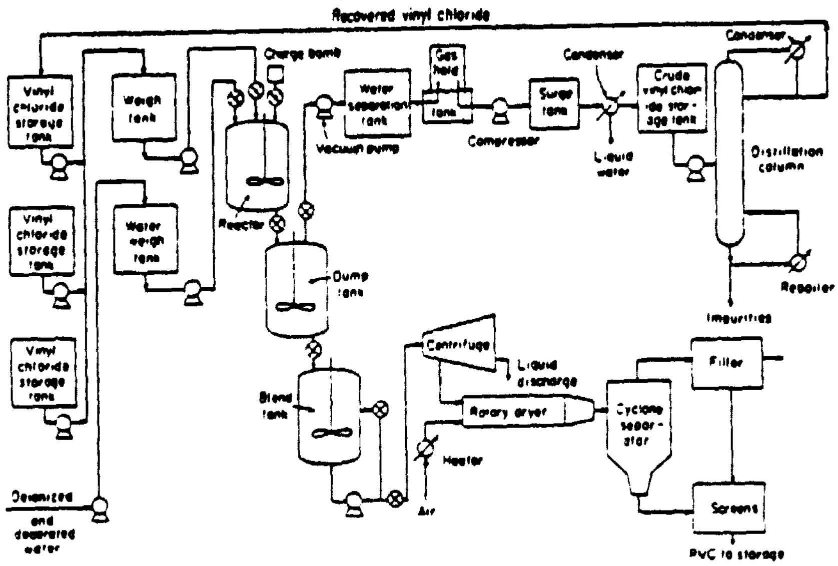


Source: Union Carbide Corp. bulletin "HDPE Production Process", 1973

EXHIBIT 2821-5

PVC, BATCH-TYPE SUSPENSION POLYMERIZATION PLANT

PROCESS FLOW DIAGRAM



SOURCE: Albright, Lyle F., Processes for Major Addition Type Plastics And Their Monomers, Mc Graw Hill, New York, 1974

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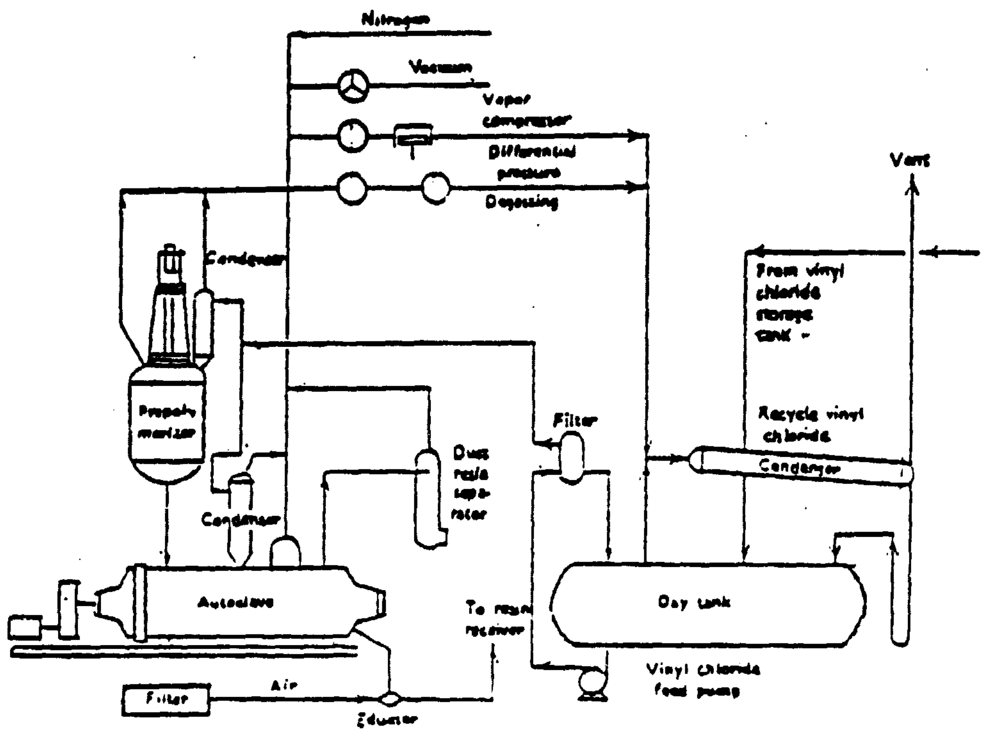
EXHIBIT 2821-6

PVC, TWO-STEP BULK POLYMERIZATION PLANT

PROCESS FLOW DIAGRAM (12)



SOURCE: Kirk-Othmer, Encyclopedia of Chemical Technology, 2nd edition, Interscience, New York, 1963-1970

EXHIBIT 2821-7

ANNUAL NATIONAL DATA (1975), SIC # 2821

LOW DENSITY POLYETHYLENE, HIGH DENSITY POLYETHYLENE, POLYVINYL CHLORIDE

	Product Production Million Ton	Total Energy[a] Consumption Trillion Btu	Purchased [a],* Electricity Trillion Btu	Purchased[a] Fuels Trillion Btu	Coal[b]	Oil[b]	Gas[b]	Other[b]	Total Energy Consumption For SIC Trillion Btu	Percent Energy Total Consumption Represented
LDPE	2.38	28.27	17.93	10.34	2.07	1.86	5.41	1.00	--	17.33%
HDPE	1.23	15.72	6.53	9.19	1.84	1.65	4.80	0.90	--	9.64%
PVC	1.82	18.83	6.54	12.29	2.46	2.21	6.43	1.19	--	11.54%
TOTAL (c) of three above	5.43	62.82	31.00	31.82	6.37	5.72	16.64	3.09	--	38.51%
TOTAL (c) for SIC 2821	11.65	163.14	24.87	138.27	27.68	24.95	72.39	13.25	163.14	100 %

(*) Purchased electricity converted at 3413 Btu/kWh

(a) An additional 83% of onsite energy use was added to account for typical offsite energy consumption in order to be consistent with Bureau of Census data. (33% for fuel and 50% for electric energy)

(b) Coal, oil, gas, and other fuels were distributed from purchased fuels using 1975, Census of Manufactures proportions.

(c) Total energy for LDPE, HDPE, and PVC can be properly compared with the total energy for the SIC, however, the breakdown of fuel and electrical energy should not be compared because plants in SIC 2821 are normally integrated with a petrochemical complex and allocation of fuels and electric energy to a process within a complex is arbitrary (i.e. allocation of onsite electrical generation).

EXHIBIT 2821-8

ENERGY CONSUMPTION PER UNIT OUTPUT: LDPE, HDPE, & PVC PRODUCTION

	Electricity Million Btu Per Ton *	Hot Water Million Btu Per Ton	(Million Btu)** To 300°F	(Million Btu)** 300-500°F	(Million Btu)** Over 500°F	Direct Fuel*** Million Btu Per Ton	Exhaust Stream Temperature °F	Exhaust Stream Energy Million Btu Per Ton
LDPE	7.53	--	0.42	3.05	--	--	--	--
HDPE	5.31	--	--	5.97	--	--	--	--
PVC	3.59	--	--	5.40	--	--	--	--

* At 3413 Btu/kWh

** Since steam temperature vary from plant to plant, no one exact temperature can be considered as completely representative and accurate for an industry. However, the following steam temperatures have been frequently observed and for the purpose of this report may be considered as characteristic for the LDPE, HDPE, and PVC processes.

Steam Temperatures (°F)

	Low Pressure	High Pressure
LDPE	280	430
HDPE	--	330
PVC	--	320

EXHIBIT 2821-9

DEMAND FOR LOW DENSITY POLYETHYLENE (2)(10)

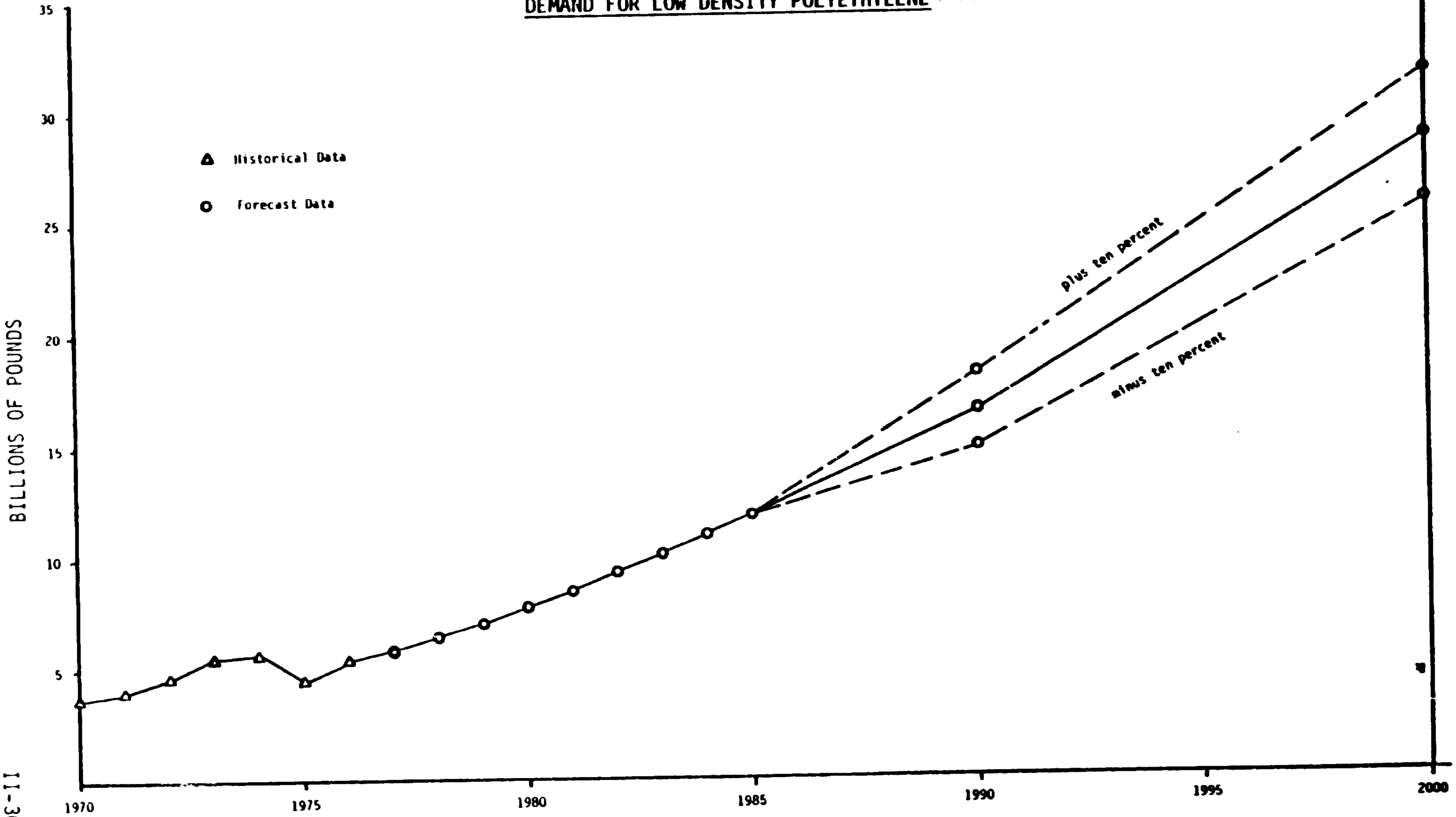


EXHIBIT 2821-10

DEMAND FOR HIGH DENSITY POLYETHYLENE(2)(10)

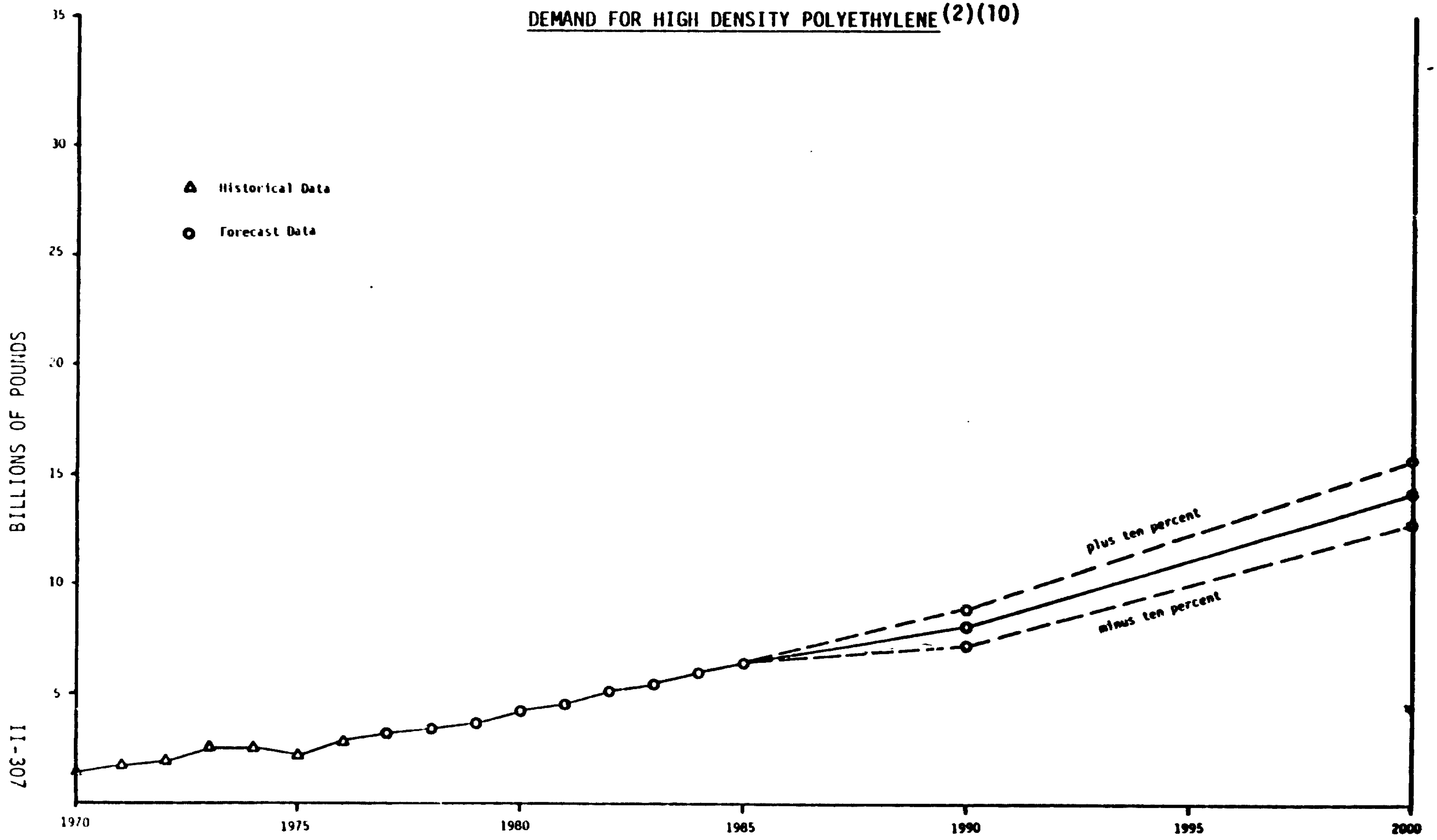


EXHIBIT 2821-11

DEMAND FOR POLYVINYL CHLORIDE(2)(10)

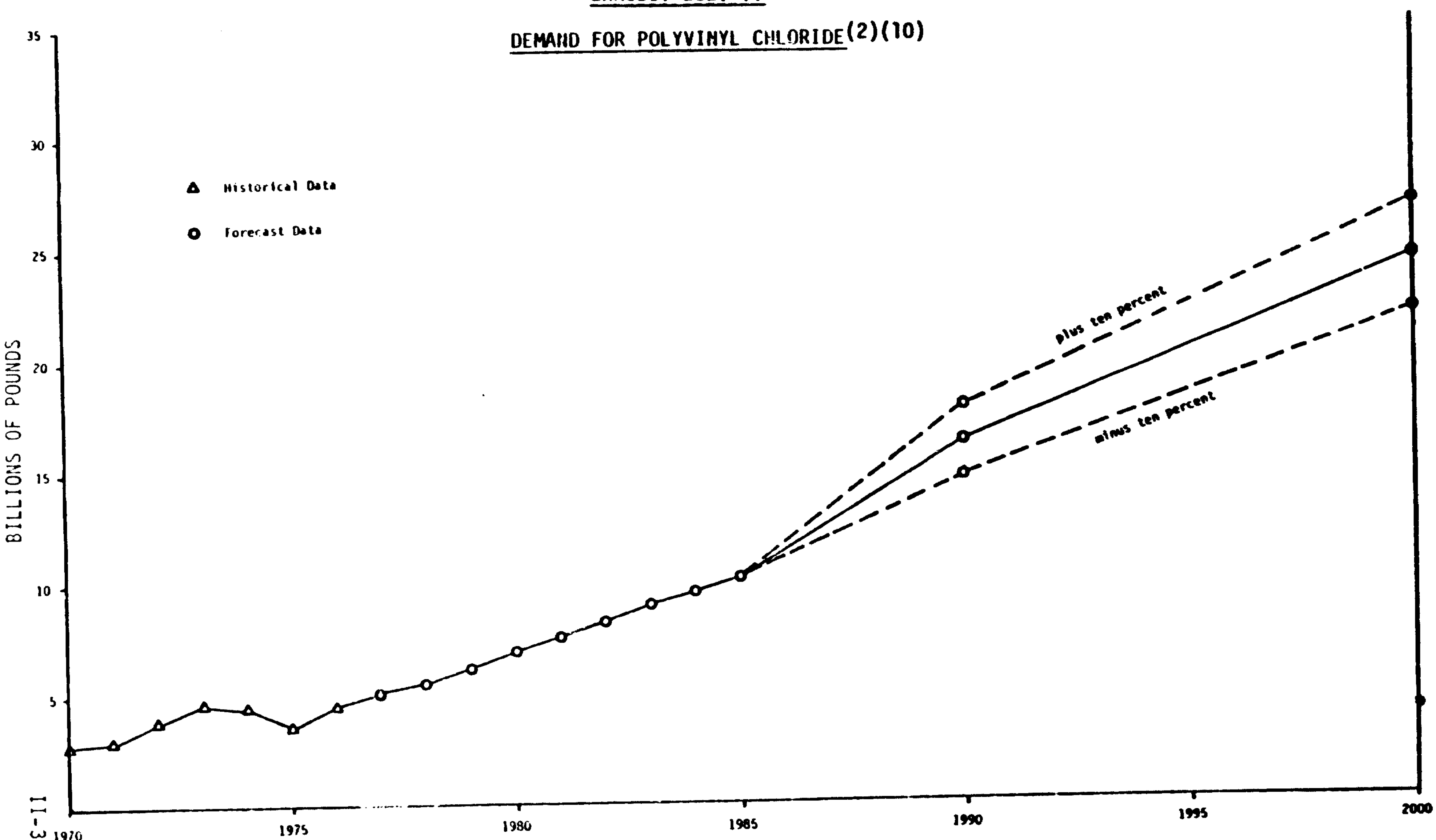


EXHIBIT 2821-12

LDPE, HDPE, and PVC Plant Factors

	TYPICAL* (16) PLANT CAPACITY TONS/YEAR	PLANT SIZE* (16) RANGE TONS/YEAR	ELECTRIC LOAD FACTOR	THERMAL ELECTRICAL COINCIDENCE FACTOR	PROJECTED APPLICABILITY TO 2000
LDPE	190,000	75,000-325,000	>0.90	0.90-1.0	190,000**
HDPE	140,000	62,500-200,000	>0.90	0.90-1.0	140,000**
PVC	120,000	25,000-160,000	>0.90	0.90-1.0	120,000**

* 1977

** Typical plant capacity projected to 2000 will be approximately the same as current (1977) typical capacities; capacity utilization is also expected to be close to 100% by 2000.

Footnotes

1. "World Chemical Outlook", Chemical & Engineering News, December 19, 1978, P-30 "C & EN's Facts and Figures for the Chemical Industry," Chemical & Engineering News, June 6, 1977, P-39.

2. "Markets for U.S. Thermoplastics", Chemical Engineering, Sept. 13, 1977, P-163

3. U.S. Dept. of Commerce, Bureau of Census, "Annual Survey of Manufactures, Fuels and Electric Energy Consumed," 1975

4. Gordian Associates, Inc., The Data Base, The Potential for Energy Conservation on Nine Selected Industries, Federal Energy Administration, June 1974

5. "1977 Petrochemical Handbook Issue," Hydrocarbon Processing, November 1977, P-204-212, 218-220

6. Solvay & Cie Sa, "Solvay HDPE Supported Catalyst Process, " 1975

7. "Polymer Purification Made Easier in HDPE Route," Chemical Engineering, April 3, 1972, P-66

8. Gordian Associates, Inc., Industrial International Data Base, The Plastics Industry, Energy Research and Development Administration, 1977

9. Albright, Lyle F., Processes for Major Addition Type Plastics and their Monomers, McGraw-Hill, New York 1974

10. Data Resources, Inc. "Petrochemical Service Review," Feb. 1977, Vol.2, No. 1

11. "What's Ahead for PVC," Hydrocarbon Processing, January 1978, P-155

12. Kirk-Othmer, Encyclopedia of Chemical Technology, 2nd Edition, John Wiley & Sons, New York, 1963-1970

13. "Chementator, Low Pressure Route to Low-Density Polyethylene," Chemcial Engineering, November 21, 1977, P-111

14. For utility requirements, see footnotes (5), (6), (7), and (8)

15. Battelle Columbus Laboratories, "Developing a Maximum Energy Efficiency Improvement Target for SIC #28", Federal Energy Administration, July 1976

16. Oil & Gas Journal, World Wide Petrochemical Directory, 1977, 15th Edition, The Petroleum Publishing Co., Oklahoma

STYRENE-BUTADIENE RUBBER (SBR)

1.0 Process Description

This section identifies the SIC classification for SBR and provides a description of its manufacturing process.

1.1 SIC Classification

The production of SBR is classified under SIC code 2822, "Synthetic Rubber (Vulcanizable Elastomers)". SIC 2822 includes many other types of Synthetic Rubber, including butyl, nitrile, and polyisoprene. (Butadiene copolymers containing less than 50% butadiene are classified in SIC 2821).

1.2 Process Description

SBR is produced by the copolymerization of styrene and butadiene. Over 90% of the production of SBR occurs by emulsion polymerization (∿75% by the "cold" SBR process and ∿17% by the "hot" SBR process) and the balance by solution polymerization.(1)* In both cases, the styrene content of the rubber is about 23%.(2)

"Cold" and "hot" SBR emulsion polymerization processes use the same equipment but with different raw materials. Cold" SBR utilizes a different catalyst system and reacts at a lower temperature (41°F) than "hot" SBR (122°F).(2) Above certain polymerization levels polymer quality deteriorates; for this reason, "cold" SBR polymerization is stopped at 60% conversion and "hot" SBR at 70-75% conversion.(2) Typical raw material formulations for "cold" and "hot" SBR emulsion polymerization are shown in Exhibit 2822-1.

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* Numbers in parenthesis indicate references listed at the end of this chapter.

As illustrated in the process flow diagram in Exhibit 2822-2, styrene and butadiene are mixed with water, an emulsifier (soap), an initiator (to start the reaction), and a modifier (to control the reaction) and then emulsified and fed to a series of reactors where the polymerization occurs. The effluent from the reactors consists of a latex* plus some unreacted butadiene and styrene. The butadiene is recovered by flashing and the styrene by steam stripping the latex under vacuum. The purge streams from each of the unreacted monomer recycle streams are returned to the supplier for purification. (Both materials are temperature sensitive and require careful fractionation under vacuum; it is therefore more economical to have the purification carried out by the supplier rather than at the SBR plant). The rubber is precipitated from the latex by the addition of brine and dilute sulfuric acid; the coagulated crumb is filtered off, washed, dried, and baled.

In many SBR plants, the latex is mixed with carbon black and/or oil prior to coagulation. Carbon black strengthens the rubber and oil "extends" the rubber, making it less expensive, while also serving as a plasticizer and softener. Mixing these materials before coagulation results in more intimate mixtures than are possible if the mixing is done by compounding with the dried crumb.[3]

Solution polymerization differs from emulsion polymerization in that the reaction takes place in the presence of a hydrocarbon solvent and in the complete absence of water. The rubber leaves the reactors in

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* Latex refers to an aqueous suspension of SBR rubber particles which have yet to be coagulated and made into finished product.[3]

the form of a solution ("cement"). Unreacted butadiene is flashed off and the cement is steam stripped to remove solvent and unreacted styrene, and to form the rubber crumb. As before, the crumb is washed, dried and baled. If oil extension is desired, the oil is added to the cement prior to steam stripping.

2.0 NATIONAL DATA

The annual national data for SBR is presented in this section. A summary of production and energy consumption is shown in Exhibit 2822-3.

2.1 Capacity and Production Data*

Summarized below is the total U.S. production and consumption for SBR and synthetic rubber (all data in million pounds):

SBR	1974	1975	1976	1977
Production[4]	3,233	2,600	2,939	--
Consumption	--	2,756[5]	2,858[6]	3,345[6]
Synthetic Rubber				
Production[7]	5,508	4,280	5,080	5,733[11]
Consumption	--	4,459[5]	4,796[6]	5,579[6]

Total U.S. SBR production capacity for 1977 totalled 3,527 MM lbs.[7] The following nine companies comprise this capacity.

1977 U.S. SBR PRODUCTION CAPACITY[7]

Producer	Capacity (MM lbs/Yr)
Goodyear	866
Firestone Tire & Rubber	772
Texas-U.S. Chemical	399
B.F. Goodrich (Ameripol)	320
American Synthetic Rubber	276
Copolymer Rubber & Chemical	276
Phillips Petroleum	274
General Tire & Rubber	212
Ashland Chemical	132
TOTAL	3,527

* Note that production data is normally reported on an "as shipped" basis, i.e., including quantities of chemical additives. Therefore, the data presented throughout this report relates to "as shipped" rubber rather than virgin rubber.

There are approximately 13 SBR plants in the U.S. with plant capacities that range from 17,000 tons/year to 364,000 tons/year. The industry-wide mean SBR plant capacity is 128,000 tons/year; for plants above 100,000 tons/year the mean capacity is 198,000 tons/year and for plants below 100,000 tons/year the mean capacity is 48,000 tons/year.[8]

2.2 Annual Energy Consumption

The U.S. Census Bureau reports energy consumption (by fuel type) for SIC 2822 in 1975.[9]

1975, ANNUAL ENERGY CONSUMPTION, SIC 2822

Energy Source	Consumption (x 10^{12} Btu)
Fuel Oil	2.00
Coal**	3.02
Natural Gas**	24.40
Other	6.07
Purchased Fuel (Total)	35.49
Purchased Electricity*	4.10
Purchased Fuels and Electric Energy (Grand Total)	39.59

* Purchased electricity converted at 3413 Btu/kWh; self-generated electricity is already included in the individual fuel consumptions above.

** Coal and natural gas consumption were witheld from the 1975 Census to avoid disclosure; however, 1972 Census proportions were applied to the known remainder of coal and natural gas consumption in 1975.

SBR represented 60.7% of the total U.S. synthetic rubber production in 1975 and 57.9% in 1976. Annual energy consumption for SBR was determined by utilizing an overall energy requirement of 9.45 MM

* Converted at 3413 Btu/kWh

Btu/Ton (0.67 MM Btu/Ton electricity* and 8.78 MM Btu/Ton fuel)[10] as explained in section three of this report.

The total purchased fuel was distributed across the various types proportionately with the 1975 Census of Manufactures data, and the resulting 1975 annual energy consumption for SBR is shown below:

1975 ANNUAL ENERGY CONSUMPTION, SBR

Energy Source	Consumption (x 10^{12} Btu)
Fuel Oil	0.64
Coal	0.97
Natural Gas	7.84
Other	1.96
Purchased Fuel (Total)	11.41
Electricity*	0.87
Purchased Fuel and Electric Energy (Grand Total)	12.28

It is interesting to note that, although SBR accounts for about 60% of the volume of synthetic rubber produced, its production accounts for only about 31% of the energy consumed in synthetic rubber production annually. The conclusion may be drawn, therefore, that the process for manufacturing SBR is significantly less energy-intensive on a unit basis than processes for other synthetic rubbers.

* Converted at 3413 Btu/kWh

3.0 PROCESS ENERGY REQUIREMENTS

The following sub-sections describe the energy requirements, thermal and electrical, per unit of production in SBR manufacture. A summary of energy requirements per unit output is presented in Exhibit 2822-4.

3.1 Unit Energy Consumption Data

SBR production is an energy intensive process requiring approximately 90% thermal energy and 10% electric energy. The subsequent section, 3.2, provides thermal and electrical energy consumption detail.

Plant energy consumption data per short ton are shown in Exhibit 2822-5; however, since there are large variations in this data, the calculation of a meaningful average which would accurately represent an SBR producing facility is prohibited. Several factors may contribute to this considerable variation in quantity and mix of unit energy consumption. Plant A, for example, requires much more energy than each of the other plants; however, this may be due to the fact that a number of different types of synthetic rubber are produced at that site. These rubbers are more energy intensive than SBR, and the reported figures may apportion a part of this energy incorrectly to SBR production. It should also be realized that the higher capacity plants operating at higher capacity utilization will be more energy efficient than lower throughput plants. Other variations in the data exist largely due to plant age. Old plants typically utilize steam for drying (an extremely energy intensive operation) while newer plants utilize mechanical (electrically driven) dryers. Typical levels of energy consumed in drying SBR as a function of plant age are illustrated in Exhibit 2822-6. Among the advantages of mechanical

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* At 3413 kWh/Btu

drying are reduced equipment size, reduced steam volume handled, and no SBR recovery problems from steam.

From Exhibit 2822-5, plant E has been selected herein as a representative plant. Plant E utility consumption data is shown below:

SBR PLANT UTILITY REQUIREMENTS*

Electricity	195.4 kWh
Steam @ 150 psi	3,375 lbs
@ 15 psi	1,310 lbs
Natural Gas	1830.4 CFT

Basis: 1.0 short ton of SBR

3.2 Details of Thermal and Electrical Energy Consumption

SBR manufacturing processes are continuous batch processes, operating 24 hrs per day, 7 days per week, all year round.

As noted in the previous section, SBR processes utilize electricity, steam, and natural gas. Steam conditions are saturated, no superheat, and SBR plants are usually adjacent to butadiene and/or styrene plants from which they may purchase steam. There is no source of by-product process fuel.

Plant equipment (pumps, fans, compressors, vacuum pumps, agitators, hydraulic systems, conveyors, etc.) are electric motor driven except for the refrigeration compressors (ammonia) and cooling water pumps. The refrigeration compressors and cooling water pumps are driven by natural gas engines. Low pressure steam (25 psi) is used to control temperature

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* On a Btu basis these utility requirements are: Electricity (@ 3413 Btu/kWh) = 0.67 MM Btu/Ton, Fuel for steam (@ 80% boiler efficiency) = 6.95 MM Btu/Ton, and Natural Gas (as direct fuel) = 1.83 Btu/Ton.

in the raw material storage and preparation/ mix tanks and to steam sparge in the styrene stripping column. High pressure steam sparges (160 psi) are used in the blowdown and reslurry tanks. The dryer is equipped with high pressure steam heating coils, air circulation fans, and exhaust fans. Cooling water is used by the reactors to control reaction temperature. All tanks including the reactors use agitators. (A process flow diagram indicating state conditions is shown in Exhibit 2822-11).

4.0 ANTICIPATED TRENDS

This section discusses trends through the year 2000. The major emphasis is on market development and trends in process technology and energy consumption.

4.1 Product Growth Trends

U.S. SBR consumption in 1977 represented 60% of all U.S. synthetic rubber (SR) consumption and 45% of all U.S. new rubber (synthetic and natural) consumption.

U.S. major end uses of SBR and all new rubber in 1977 are shown below:

U.S. RUBBER END USE - 1977 (6)(7)

	SBR	New Rubber**
Tires	68.0%	65.0%
Mechanical Goods	13.0%	18.5%
Latex Foam Products	4.0%	3.5%
Footwear	3.0%	6.0%
Miscellaneous	12.0%	7.0%*
	100.0%	100.0%

* Includes 1.0% for end use in wire and cable.

** 71.3% and 79.9% of all new rubber consumed in 1976 for tire end use and non-tire end use, respectively, is synthetic rubber.

Projected SBR, SR, and NR* consumption from 1976 through 1985 and 2000 is estimated in Exhibit 2822-7 and tabulated below:

CONSUMPTION
(Billions of Pounds)

	Historical	Forecast			
	1976 (6)	1977 (6)	1978 (6)	1985 (12)	2000 (12)
SBR	2.86	3.35	3.31	3.71	5.22
SR	4.80	5.58	5.46	6.86	9.65
NR	1.61	1.86	1.82	2.15	2.77

* Natural Rubber

Recent trends in SBR and SR reflect a comeback from the 1975 recession and 1976 United Rubber Workers strike. The rebuilding of tire inventory is expected to create record breaking SBR production levels in 1977, tapering off in 1978. From 1978 to 1985, consumption of SBR, SR, and NR is expected to grow by 1.64%, 3.32% and 2.8% per year, respectively, and from 1985 to 2000, SBR, SR and NR consumption is expected to grow by 2.3%, 2.3%, and 1.7% per year respectively.[12]

Since SBR consumption trends are most affected by competition from other rubbers (synthetic and natural) and by the extent of its use in tires (40% of the total hydrocarbon content per tire is SBR[13]) it is necessary to consider factors affecting these other rubbers and tires as factors affecting SBR. Factors expected to adversely affect future SBR and SR markets and production are:

- Raw material feedstock dependence on imported oil, resulting in higher prices, may upset SR in favor of NR. Currently, the butadiene monomer supply is critically tight; 48% of all U.S. butadiene is used in SBR manufacture[14].
- Greater stability of NR supplies and price. (New technology has recently been developed for increasing crop yields.)
- Radial tires, increasingly popular and dominating the original equipment (new car tires) market, wear longer and use more NR than non-radials thereby reducing tire sales and hence, reducing SBR and SR consumption. In addition, radials are expected to generate greater relative consumption of isoprenic rubbers after 1980, when sufficient isoprene monomer may be available.
- Increasing small car use, maintenance of lower speed limits, and discouragement of car use in urban centers will also decrease tire sales and hence, SBR and SR consumption.
- Overcapacity plaguing the SBR and tire industry in all but the most extreme periods of heavy production.
- Competition from foreign producers.

- Competition from new synthetic elastomers (SBR in wire and cable is being replaced by new materials such as cross-linked polyethylene (XLPE) and PVC.
- Potential health hazard; recent suspicion of carcinogenity of chemicals used in SBR manufacture is being investigated.[15]

On the positive side, future SBR and SR markets and production will be favorably affected by:

- Increased rubber consumption due to the development of less industrialized countries.
- Growing usage of rubber in particle product forms
- Development of new applications in non-tire fields
- At present, SBR remains cheaper than NR, polyisoprene (PI) rubber, and ethylene-propylene (EPDM) rubber.

4.2 Process Changes and Implementation of New Technology

Since the sale of the government SBR plants, just after World War II (1946-1955), many process changes were made to increase capacity and improve product quality. Today, however, with acceptable product quality and excess capacity, few or minor process changes or new technologies are expected except for the increasing use of solution polymerization and changeover to the more energy efficient mechanical type drying, found in the newer plants.

Solution polymerized SBR has several improved properties over emulsion SBR, including better abrasion resistance, better flex, higher resilience, and lower heat build-up. Other physical properties, such as tensile strength, modulus, elongation, and cost are comparable. Thermoplastic type polymers can also be produced but these are not recommended for tire use.[2] Major process advantages are: increased equipment flexibility (for the production of other types of rubbers) and elimination of water

pollution (substantial in emulsion polymerization). Although the solution SBR process is more energy intensive, any new SBR capacity is expected to be solution-based as a result of the more desirable solution SBR properties. It is also likely that future development of the solution process will achieve lower energy consumption levels than currently prevalent for the process. For 1985 it is estimated that 15% of the total SBR capacity will be solution-based.

Trends in new drying techniques have shown considerable energy savings (as shown in Exhibit 2822-6) and are characterized by the following three types of techniques for older, intermediate, and newer plants.

The drying process in older plants (i.e. built before 1950) is characterized by vacuum filtration of the coagulated crumb (down to about 35 percent water) followed by an apron (also known as a tunnel, or belt) dryer. The energy for drying in such installations is provided mostly by steam.

Plants of intermediate age are generally characterized by a dewatering screen and press for removal of most of the water from the crumb (down to about 10-15 percent water), followed by an apron dryer. Use of the screen and press results in the substitution of electric energy for part of the steam which would have otherwise been required for vacuum filtration and drying.

The newest, most modern installations feature completely mechanical drying. Thus the energy requirement is almost completely satisfied by electricity.

Other process changes, considered minor, are effected by altering process chemistry. Recently, for example, peroxide curing of rubber has been shown to upgrade the performance of rubber[(16)] and SBR latex output

can be increased either by speeding up the emulsion polymerization or by running at higher hydrocarbon-water ratios.[17]

4.3 Trends in Energy Requirements

As shown in Section 2.2, natural gas is by far the preferred energy source in the SBR industry at present. However, because of the trend towards mechanical (i.e. electrically-driven) equipment for drying SBR, it is likely that a slightly larger portion of the energy consumed per ton of SBR will come from electricity in the future. This trend will probably occur very slowly because of the low projected growth rate for SBR. Furthermore, because of the existence of a large amount of capacity utilizing steam drying, future addition of SBR plants employing mechanical drying will have limited impact on the industry's "average" mix of energy sources. Future shortages of natural gas may accelerate this effect, but the many uncertainties regarding present and future energy supplies make it difficult to quantitatively estimate future trends in energy type "mix".

From the development of an energy conservation target for the Department of Energy for SIC #28, an energy conservation target for SIC #2822 of 19.6% for 1980, relative to 1972 energy consumption levels,was estimated. For SBR production, taking into account the slowly increasing use of mechanical drying and the trend towards solution SBR, a specific energy conservation target was also estimated at 15.0%.

Based on this target, it is reasonable to expect a 15% reduction in unit energy consumption by 1985, relative to 1975 levels. With regard to the year 2000, two offsetting factors must be considered. Increased usage of the solution process will tend to increase the average energy

needed per ton of SBR, but the anticipated drop in market share for SBR will encourage producers to reduce all operating expenses to the maximum extent possible in order to compete effectively with other types of rubber. On balance, it is projected that an additional 15% reduction in unit energy consumption between 1985 and 2000 is feasible.

The total energy consumption including a breakdown showing fuel and electric energy consumed is estimated below.

ENERGY CONSUMPTION TRENDS, 1975-1985-2000
STYRENE-BUTADIENE RUBBER PRODUCTION

X 10^{12} Btu	1975	1985	2000
Total Purchased Fuel and Electricity	12.28	14.90	17.26
Purchased Fuel	11.41	13.84	16.04
Purchased Electricity*	0.87	1.06	1.22

UNIT ENERGY CONSUMPTION-SBR

X 10^{6} Btu/ton	1975	1985	2000
Total Purchased Fuel and Electricity	9.45	8.03	6.61
Purchased Fuel	8.78	7.46	6.14
Purchased Electricity*	0.67	0.57	0.47

* At 3413 Btu/kWh

5.0 PLANT SPECIFIC DATA

This section provides available data relating to specific plant energy requirements, load profiles, state conditions, and reliability considerations. Several plant factors are summarized in Exhibit 2822-8.

5.1 Load Profiles

SBR processes are continuous, operating 24 hours per day, 7 days per week, hence, load profiles generally show little variation. Exhibit 2822-9 illustrates that a typical plant has an electrical load factor of approximately 90%.

Exhibit 2822-10 shows month by month details of energy consumption (electricity, steam, and gas) for a typical plant in 1973. In this plant, steam is used at two levels (25 psig and 160 psig), steams conditions are saturated (no superheat), and steam demand is essentially constant with the plant operating 24 hours per day.

Since operation is continuous, thermal-electrical coincidence factors are estimated to be in the range of 0.90 to 1.0.

5.2 Energy Flow, Mass Flow, and State Conditions

As noted in Section 3.2, electricity, steam, and natural gas are used in SBR production, with no source of in plant by-product fuel. Electric energy is used for driving plant equipment (pumps, fans, compressors, vacuum pumps, agitators, hydraulic systems, conveyors, etc.); natural gas is used in natural gas engines which drive ammonia refrigeration compressors and cooling water pumps (by reduction gears); low pressure steam is used for controlling temperature in raw material storage and

mix tanks and for steam sparging in the styrene stripping column, high pressure steam is used to sparge in the blowdown and reslurry tanks and in the heating coils in the dryer (steam and electric energy consumed for drying in plants of various ages is shown in Exhibit 2822-6 and discussed in Sections 3.1 and 4.2). A process flow diagram presenting data on process temperatures, flows, and pressure levels for an emulsion polymerization process is shown in Exhibit 2822-11.

A simplified material balance and flow diagram for SBR manufacture is shown in Exhibit 2822-12. This can be used for computations of capacities and for sizing of a typical SBR plant.

In Section 3.1, typical process utility requirements are shown (steam, electricity and natural gas per unit output) and in Exhibit 2822-5, utility data for a variety of plants is shown. Also, illustrated in Exhibit 2822-4 is the energy consumption (BTU) per unit output (tons).

5.3 Reliability Considerations

Continuity of operation in the reaction process is a prerequisite for the production of quality latex. Any loss of electric power, refrigeration or instrument air is immediately reflected in a deviation in the chemical and physical properties of the product. The degree of deviation in product properties is directly related to the time period over which the process is upset. For utility outages under five minutes duration, latex quality will probably suffer no serious degradation. When utility outages occur for periods in excess of thirty minutes, the in-process latex is a total loss. Since the reaction time is on the order of eight hours, when a prolonged utility outage occurs, the direct

loss is one-third of a day's production plus the production lost during the utility outage and the subsequent delay in start-up. In addition to the loss in production due to an extended utility failure, there is the loss equivalent to the value of all process charge material for a period of some eight hours. Utility outages of natural gas (for refrigeration) and electricity (for pumping, agitation and instrument air) are critical.

EXHIBIT 2822-1

TYPICAL FORMULATIONS FOR "COLD" AND "HOT" SBR EMULSION POLYMERIZATION
(lbs/100lbs monomer)

	"Cold" SBR	"Hot" SBR
Butadiene	71.0	75.0
Styrene	29.0	25.0
*n-Dodecyl Mercaptan	--	0.5
**tert-Dodecyl Mercaptan	0.18	--
*Potassium Peroxydisulfate	--	0.3
**P-Menthane Hydroperoxide	0.08	--
**Ferrous Sulfate ($FeSO_4 \cdot 7H_2O$)	0.03	--
**Trisodium Phosphate ($NA_3PO_4 \cdot 10H_2O$	0.50	--
**Tetrasodium Salt of Ethylenediamine Tetracetic Acid (EDTA)	0.05	--
Sodium Formaldehyde Sulfoxylate	0.08	--
Resin Acid Soap	4.5	5.0
Water	200.0	180.0

* In "hot" SBR polymerization, the mercaptan has the dual function of furnishing free radicals (initiator) by reaction with peroxydisulfate and also of limiting the molecular weight of the polymer (chain transfer agent or modifier).

** In "cold" SBR polymerization, initiation results from the reaction of iron and hydroperoxide; the phosphates and EDTA act as buffers, the mercaptan acts as a modifier.

Source: Morton, M., Rubber Technology, 2nd Edition, Van Nostrand Reinhold, New York, 1973

EXHIBIT 2822-2

STYRENE-BUTADIENE RUBBER, PROCESS FLOW DIAGRAM
EMULSION POLYMERIZATION

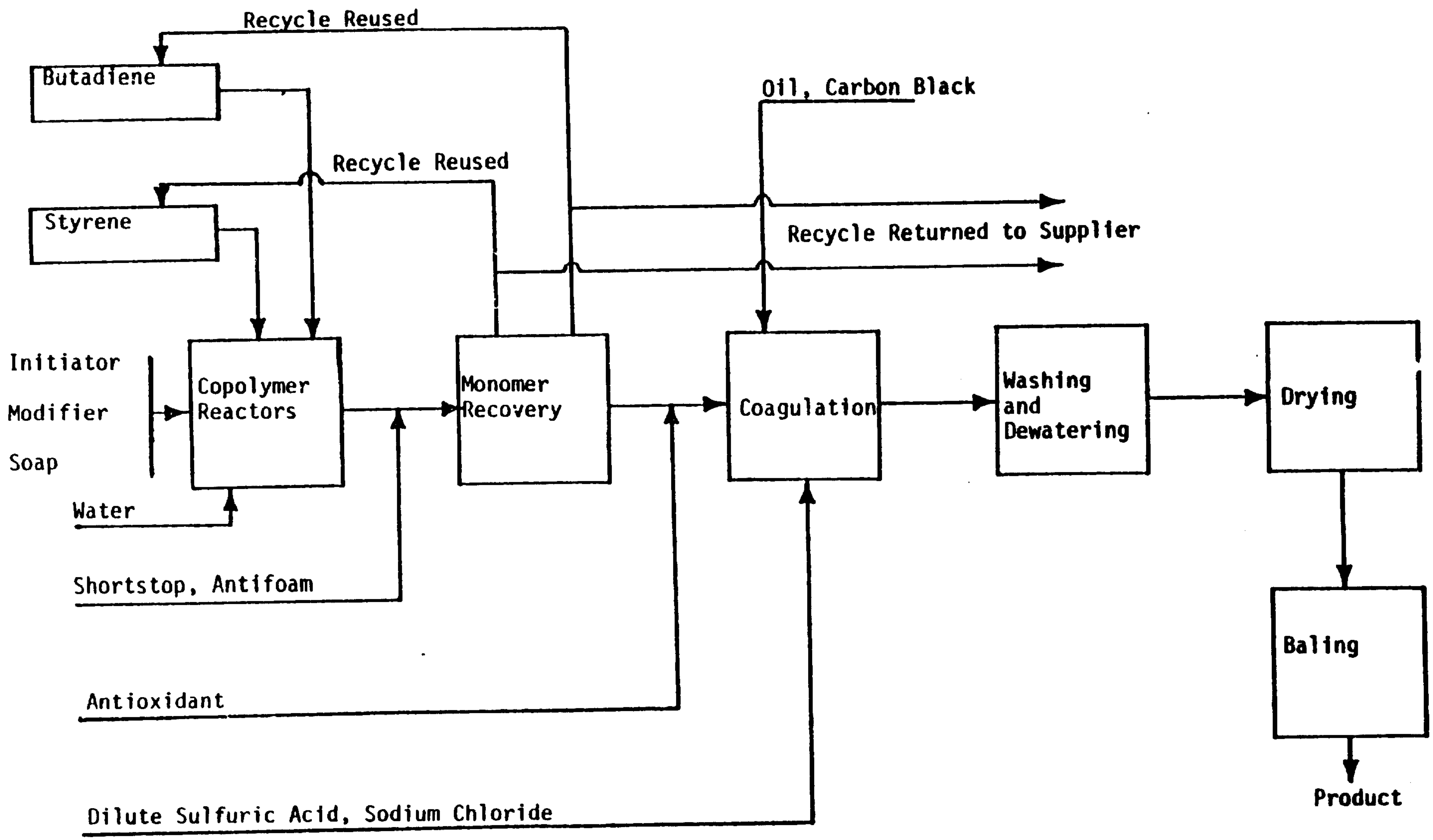


EXHIBIT 2822-3

ANNUAL NATIONAL DATA (1975), SIC 2822 STYRENE-BUTADIENE RUBBER

	Product Production Million Ton	Total Energy Consumption Trillion Btu	Purchased* Electricity Trillion Btu	Purchased Fuels Trillion Btu	Coal[a]	Oil[a]	Gas[a]	Other[a]	Total Energy Consumption For SIC Trillion Btu	Percent Energy Total Consumption Represented
Total for SBR	1.30	12.28	0.87	11.41	0.97	0.64	7.84	1.96	--	31.0%
Total for SIC 2822	2.23	39.59	4.10	35.49	3.02	2.00	24.40	6.07	39.59	100%

(*) Purchased electricity converted at 3413 Btu/kWh

(a) Coal, oil, gas, and other fuels were distributed from purchased fuels using 1972 and 1975 Census of Manufactures proportions.

EXHIBIT 2822-4

ENERGY CONSUMPTION PER UNIT OUTPUT: STYRENE-BUTADIENE RUBBER

Electricity Million Btu Per Ton*	Hot Water Million Btu Per Ton	(Million Btu)			Direct Fuel** Million Btu Per Ton	Exhaust Stream	
		To 300°F	300-500°F	Over 500°F		Temperature °F	Energy Million Btu Per Ton
0.67	--	1.51	4.05	--	1.83	--	--

* At 3413 Btu/kWh

** Natural gas, for natural gas engine refrigeration compressors (ammonia).

EXHIBIT 2822-5

ENERGY CONSUMPTION IN SBR PRODUCTION(10)

Plant	Electricity (kWh/Ton)	Fuel (MMBtu/Ton)*	Notes
A	520.0	18.75	12,300 lb. of 400 psi steam purchased per ton of SBR, plus 187.2 CFT of gas per ton SBR.
B	271.9	9.16	Steam pressure not indicated, nor breakdown between steam and fuel.
C	380.0	10.64	Steam pressure not indicated, nor breakdown between steam and fuel.
D	214.0	8,43	3,726 lb. of 150 psi steam purchased per ton of SBR, plus 2860 CFT of gas per ton SBR.
E	195.4	8.78	3,375 lb. of 150 psi steam plus 1,310lb. of 15 psi steam purchased per ton SBR, plus 1830.4 CFT of gas per ton SBR.

* Steam has been converted to equivalent fuel assuming a boiler efficiency of 80%.

EXHIBIT 2822-6

ENERGY USED FOR DRYING OF SBR[10]*

Plant Age	Steam (lb.)	Electricity (kWh)	Total** (MMBtu)
Old*	4000	167	6.5
Medium*	1600	173	3.7
New*	133	208	2.3

* Based on a 30,000 ton per year plant.

** Steam at 1195.5 Btu per lb. and electricity at 10,342 Btu per kWh.

EXHIBIT 2822-7

CONSUMPTION OF RUBBER

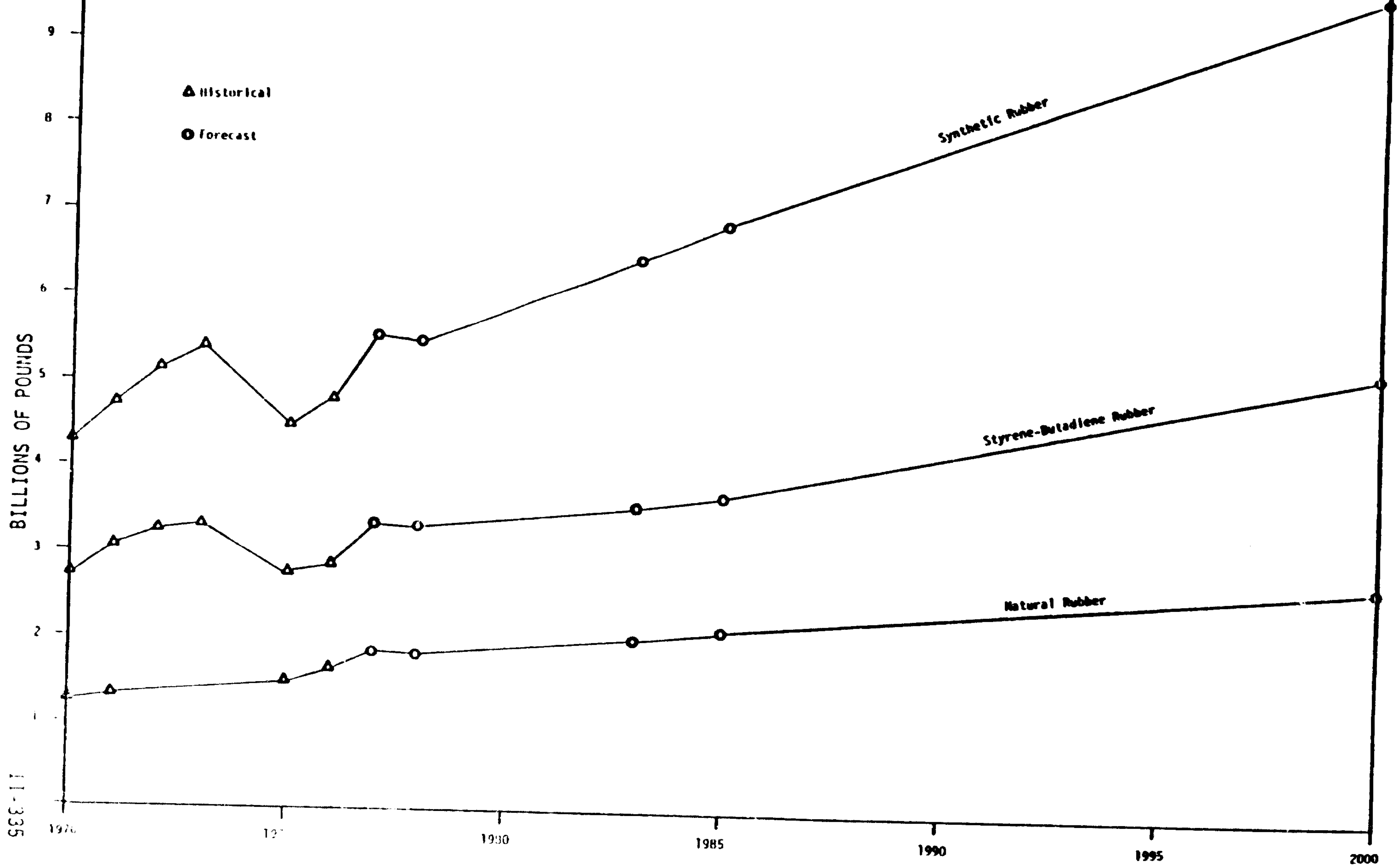


EXHIBIT 2822-8

STYRENE-BUTADIENE RUBBER PLANT FACTORS

TYPICAL [8] PLANT CAPACITY TONS/YEAR	PLANT SIZE [8] RANGE TONS/YEAR	ELECTRIC LOAD FACTOR	THERMAL ELECTRICAL COINCIDENCE FACTOR	PROJECTED APPLICABILITY TO 2000
128,000*	17,000-364,000	0.90	0.90-1.0	128,000**

* There are approximately 13 SBR plants in the U.S. with plant capacities that range from 17,000 tons/year to 364,000 tons/year. The industry-wide mean SBR plant capacity is 128,000 tons/year; for plants above 100,000 tons/year the mean capacity is 198,000 tons/year and for plants below 100,000 tons/year the mean capacity is 48,000 tons/year.

** Typical plant capacity projected to 2000 will be approximately the same as current typical capacities since the SBR industry is already burdened with overcapacity and solution SBR is expected to make up any new SBR capacity in the future.

EXHIBIT 2822-9

STYRENE-BUTADIENE RUBBER PLANT DATA
DAILY ELECTRICAL LOG OF DEMAND AND ENERGY

FEBRUARY 1973				JULY 1973		
KW		MKWH	Date	KW		MKWH
MAX	MIN			MAX	MIN	
4920	4500	120	1	4800	4380	112
4860	4500	120	2	4980	4380	124
4680	4020	90	3	4740	4260	110
4620	4080	134	4	4740	4260	114
4630	4080	106	5	4860	4440	134
4740	4260	112	6	4620	4260	92
4620	3900	112	7	4740	4200	110
4680	3960	106	8	4800	4380	136
4560	4080	110	9	4800	4320	96
4620	4200	114	10	4680	4200	110
4580	4200	110	11	4500	4080	108
4300	4320	114	12	5400	3960	118
4800	4320	116	13	4800	4200	112
4620	4140	112	14	4860	4380	113
4630	4260	101	15	4200	4500	113
4620	4320	114	16	4620	4220	114
4520	4260	110	17	2800	4080	110
4740	4260	116	18	4360	4320	116
4600	4250	114	19	4980	4380	118
4800	4380	116	20	4920	4380	113
4800	4320	116	21	5040	4440	118
4740	4330	116	22	4360	4260	120
4800	4080	110	23	4860	4500	112
4740	4020	114	24	4800	4260	114
4620	4140	108	25	4740	4200	112
4320	3840	104	26	4740	4320	116
4320	3660	102	27	4860	4560	124
4500	3840	104	28	4800	4440	124
			29	4800	4200	108
			30	4560	4080	102
			31	4800	4260	120
4675 Avg.	4170 Avg.	3130		Hi 4659 Avg.	Lo 4326 Avg.	3564
4422.5 Avg.				4492.5 Avg.		

EXHIBIT 2822-10

STYRENE-BUTADIENE RUBBER PLANT DATA

1973 ANNUAL UTILITY USAGE

Month	Per M Pounds Product			
	Elect.	Gas	Steam	
	KWH	CF	25# lbs.	160# lbs.
Jan	97.141	712.80	733.60	2259.49
Feb	90.629	731.11	667.18	2292.46
Mar	95.841	764.87	672.39	2061.12
Apr	94.984	821.63	648.82	2045.15
May	93.512	859.82	603.37	1950.31
Jun	100.549	999.74	549.06	1929.38
Jul	99.556	833.43	395.86	1807.08
Aug	104.479	910.04	323.56	2004.23
Sep	93.431	788.13	374.62	1783.58
Oct	102.093	826.04	487.95	2136.10
Nov	96.109	883.88	431.86	1897.95
Dec	91.866	741.77	487.34	2022.80
Monthly average for the year	96.476	819.163	535.967	1997.62

PROCESS FLOW DIAGRAM

EXHIBIT 2822-11

SBR-EMULSION POLYMERIZATION

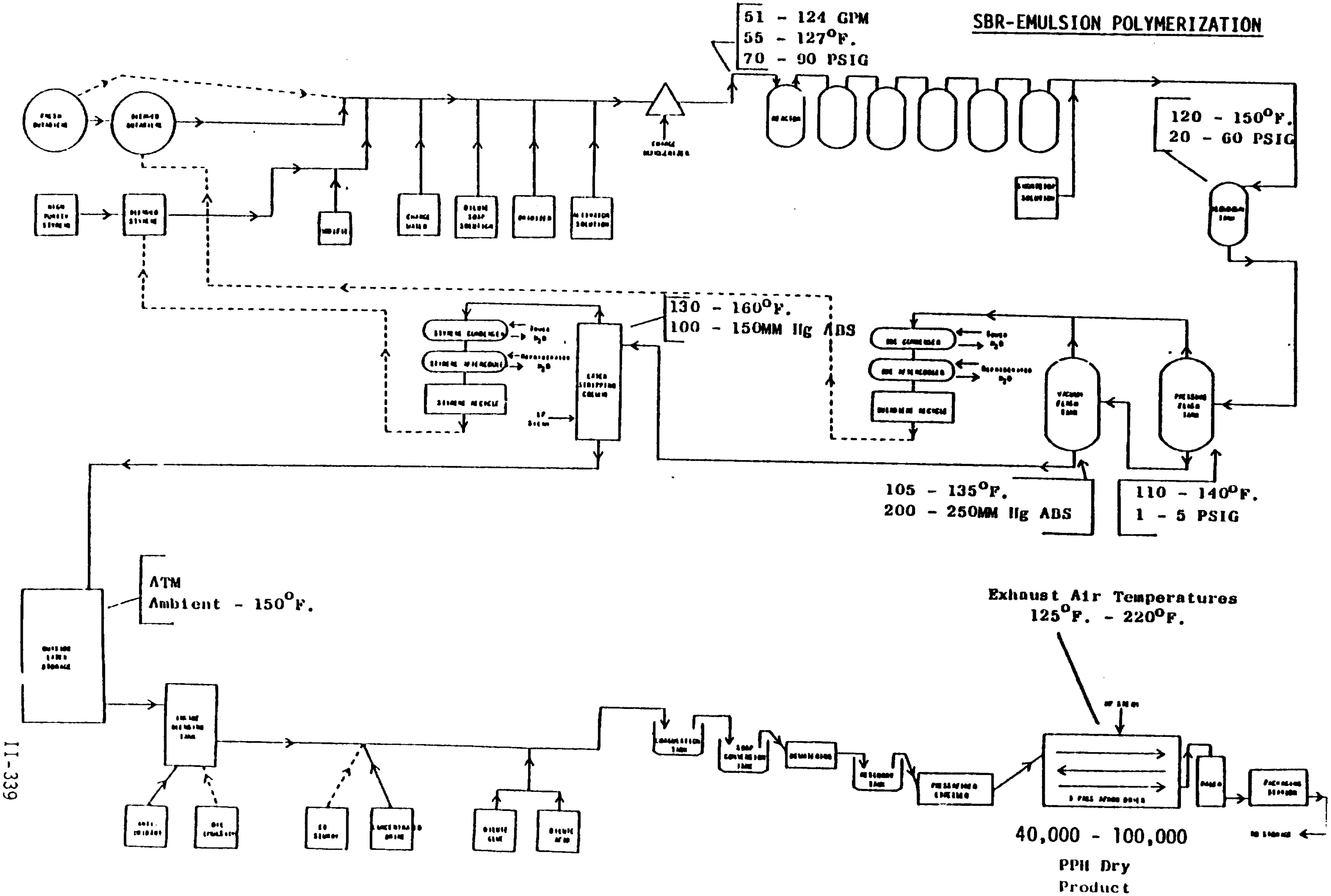
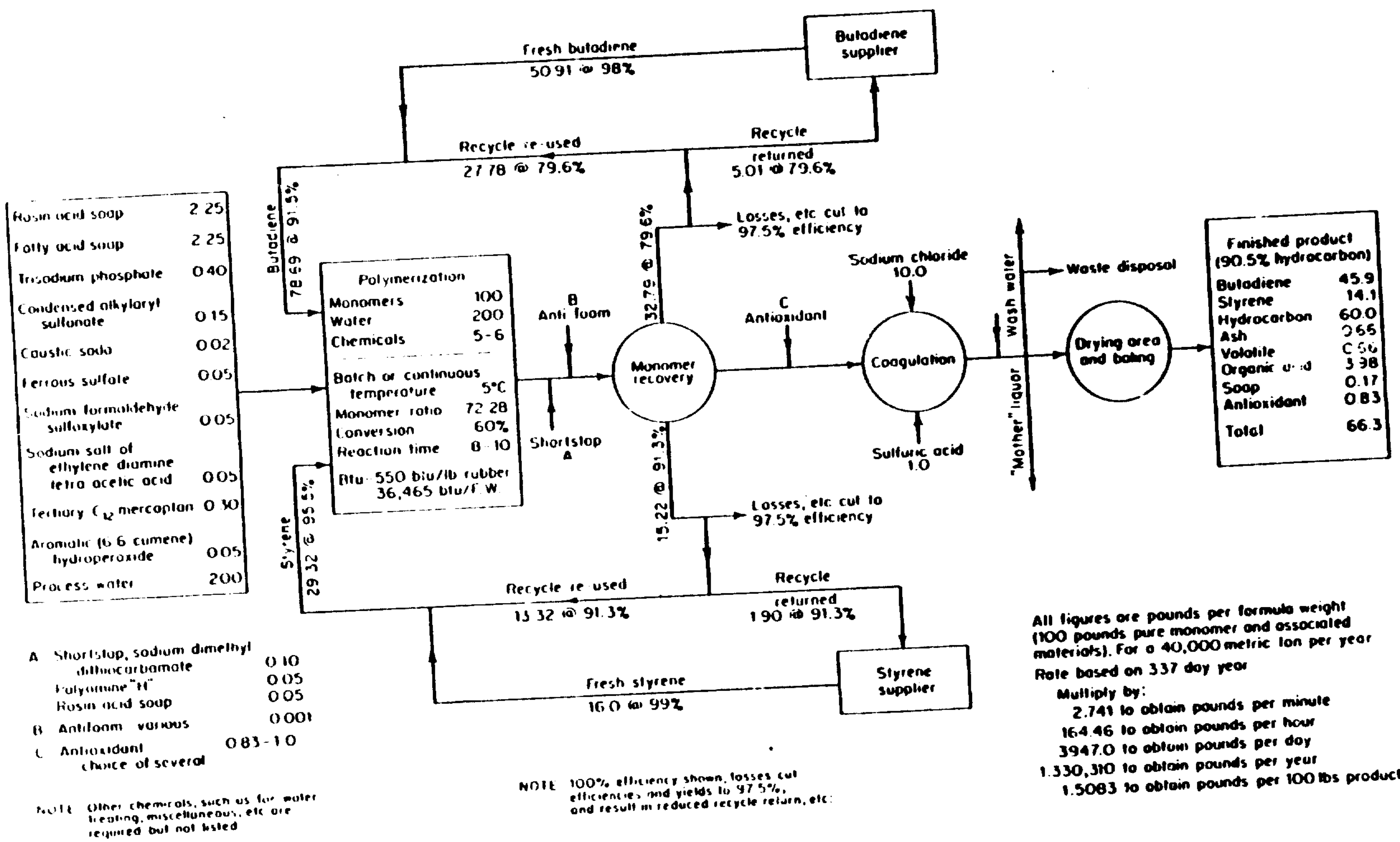


EXHIBIT 2822-12

STYRENE-BUTADIENE RUBBER
MATERIAL BALANCE AND FLOW DIAGRAM



Source: Shreve, R.N., Chemical Process Industries, McGraw-Hill, New York, 1977, p. 640.

FOOTNOTES

(1) Battelle Columbus Laboratories, "Developing a Maximum Energy Efficiency Improvement Target for SIC #28", Federal Energy Administration, July 1976.

(2) Morton, M., Rubber Technology, 2nd Edition, Van Nostrand Reinhold, New York, 1973.

(3) Shreve, R.N., Chemical Process Industries, McGraw-Hill, New York, 1977.

(4) "C & EN's Facts and Figures for the Chemical Industry", Chemical and Engineering News, June 6, 1977, p. 39.

(5) Elastomerics, Palmerton Publishing, January, 1977, p. 27.

(6) Elastomerics, Palmerton Publishing, January 1978, p. 20.

(7) Chemical Marketing Reporter, Schnell, New York, March 14, 1977, p. 9.

(8) Rubber World, New York, Vol. 162, No. 5, Aug. 1970, p. 57-58.

(9) U.S. Department of Commerce, Bureau of Census, "Annual Survey of Manufactures, Fuels and Electric Energy Consumed", 1975.

(10) Gordian Associates industry survey.

(11) Gordian Associates, Inc., The Data Base, The Potential for Energy Conservation in Nine Selected Industries, Federal Energy Administration, June 1974.

(12) European Chemical News, IPC Industrial Press, London, January 6, 1978, p. 6.

(13) Dworkin, David, "Tires", Chemical Week, McGraw-Hill, New York, May 19, 1971, p. 37.

(14) Chemical Marketing Reporter, Schnell, New York, March 28, 1977, p. 30, 32.

(15) "Chementator, Cancer Scare Hits Rubber Industry", Chemical Engineering, McGraw-Hill, New York, April 12, 1976, p. 61, 62.

(16) Elastomerics, Palmerton Publishing, July, 1977, p. 19-26.

(17) Chemtech, American Chemical Society, Washington, D.C., August, 1977, p. 465.

NYLON

1.0 PROCESS IDENTIFICATION

This section identifies the SIC classification for nylon and provides a description of its manufacturing process.

1.1 SIC Classification

The production of nylon is classified under SIC code 2824, "Synthetic Organic Fibers, except cellulosic". End product is in the form of monofilament, yarn, staple, or tow* suitable for further processing on textile manufacturing equipment (i.e., looms, knitting machines, etc.). Other major synthetic fibers produced under this SIC are polyester, acrylic, and polyolefin.

1.2 Process Description

Primary production of nylon in the U.S. is of two forms: nylon 6,6 and nylon 6. Although their physical properties are similar, nylon 6,6 is generally preferred: 70% of all U.S. nylon produced is nylon 6,6 while the remaining 30% is nylon 6; other nylons represent negligible amounts.

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* Monofilament - a single filament (fine thread) of continuous length.

Yarn - multifilament, two or more continuous monofilaments assembled or held together by twist or otherwise.

Tow - large bundles of continuous monofilaments assembled without a twist.

Staple - discontinuous lengths of fibers which have been cut or broken into desired lengths from large bundles of continous monofilaments (tow).

Nylon 6,6 is produced from the reaction of adipic acid and hexamethylenediamine (HMDA). An intermediate product, nylon salt (hexamethylenediammonium adipate), is formed from which nylon 6,6 is polymerized by condensation (removal of water by-product). Nylon 6, on the other hand, is produced by the polymerization of caprolactam under the influence of a catalyst. Water-catalyzed polymerization is the most widely used method for nearly all fiber production. Caprolactam and water are mixed together and heated, whereupon the caprolactam is hydrolyzed by the water and then polymerized via condensation reaction. For both nylon 6,6 and nylon 6, the reactions are carried out in an inert atmosphere (to prevent discoloration and degradation of other properties) and the polymer may be spun or formed into fibers directly following polymerization (continuous process) or into chips to be remelted and spun into fibers later (batch process). A more detailed process description of the common industrial processes for nylon 6,6 and nylon 6 production follows.

Nylon 6,6

Nylon 6,6 fiber industrial production is broken into three parts: preparation of the nylon salt from adipic acid and HMDA, polymerization of the nylon salt, and spinning and drawing* the nylon polymer into fibers.

Nylon salt production (Exhibit 2824-1) is a simple batch process. Adipic acid and HMDA are separately dissolved in methanol (at about 40°C) in two steam jacketed agitated vessels, with an inert (nitrogen)

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* Nylon fiber is "drawn" or stretched, thereby orienting polymer molecules to create increased tensile strength and reduced elongation.

atmosphere. The two solutions are transferred to an agitated, cold water jacketed, autoclave reactor where the exothermic reaction is controlled at approximately 60°C as the insoluble nylon salt precipitates from methanol solution. The slurry is transferred to a holding or surge tank from which it is centrifuged. The remaining nylon salt cake is washed several times with methanol to remove unreacted adipic acid and HMDA. The mother liquor, from the centrifugation, and the methanol filtrate, from the washing, are purified in a distillation column and evaporator for methanol and nylon salt recycle and recovery.

The nylon salt cake is then dumped into a tank and dissolved in purified (deionized or distilled) water. The aqueous solution of 50% nylon salt is now ready for the polymerizer.

Nylon 6,6 polymerizers have evolved into a number of different polymerizer reactor designs, each design with different characteristics of energy consumption and product quality control. Most representative of the industry are the autoclave batch reactor and tubular continuous reactor design, each estimated to contribute equally to industry capacity.[5]

In the batch process (Exhibit2824-2), nylon salt is concentrated from 50% to 80% salt in an evaporator charged with an inert gas. Additives (stabilizers, pigments such as titanium dioxide, etc.) may be added at the separator (and/or reactor). The salt solution is then transferred to an autoclave reactor where it is polymerized in five process steps.

1) Raise pressure to 250 psig @ 150-230°C.

2) Vent by-product water as polymer temperature gradually increases to 250°C.

3) Reduce pressure from 250 psig to 0 psig while polymer temperatures goes to 270°C.

4) At 0 psig, heat at 270°C-275°C for about 30 minutes.

5) Discharge.

In the final step, the polymer is extruded and cast into a hard "ribbon" then chopped into polymer chips and stored or blended with other polymer chips for remelting and use later. Total process residence time is from 3 to 5 hours depending on the operating conditions chosen and product quality desired.

The tubular reactor process (Exhibit 2824-3), like the batch process, requires an evaporator to concentrate and heat the nylon salt solution, from 40°C (@ 50% salt) to 125°C (@70% salt). The nylon salt solution is heated further (by a coiled tube heat exhanger) as it is transferred to the tubular reactor where it is allowed to polymerize (polycondensation) while the temperature increases (from 210°C to 250°C @ 250 psig). The reaction is controlled by the removal of by-product water. Additives are added in line before and/or after the reactor. A flasher is used to reduce pressure (to 0 psig) and raise temperature (to 280°C) enroute to the separator. In the separator water vapor is removed, residence time (viscosity) is increased, and the polymer is transported by screw conveyor to the finisher. The finisher removes any residual water, adds the final control over viscosity and molecular weight, raises the temperature to 290-295°C (the desired polymer spinning temperature), and transports the polymer by screw conveyor to positive displacement pumps which feed the spinning machine(s) (continuous polymerizers usually feed molten polymer directly to spinning machines).

The formation of nylon polymer into fiber is done on spinning machines. These can be fed molten polymer directly from a continuous polymerizer or from nylon chips, remelted, as formed in the batch process.

Current technology has been able to combine the spinning and drawing process into one operation, hence, one machine.

From the batch process, nylon 6,6 chips are melted on consecutively staged heated grids and transported to the spinning machine(s) by a screw. The process equipment for this is collectively called a "screw-melter".

A spinning machine consists of many sites (as many as 30) where nylon polymer is spun into fiber and wound-up onto spools or tubes, and as many as 12 threadlines (multifilament fibers) may be wound per site depending on the denier.* Each site consists of a positive displacement metering pump, a distribution plate, filter(s), spinnerets(s), a quenching duct, drawing rolls, and winding or take-up rolls. The metering pump delivers the molten polymer through the distribution plate and filter(s) to the spinneret(s)**. The spinneret is a metal plate of corrosion resistant alloy with one to literally thousands of tiny holes through which the molten polymer is forced and extruded into fiber form. The newly formed fiber, still molten, is immediately quenched by a cross current of cool air, (this process is called "melt-spinning"). The fiber is wrapped around several revolving rolls on its way to the take-up spool and is drawn between two or three of the rolls, the down-line roll

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* Denier refers to the thickness of the fiber or threadline (monofilament, multifilament, or cut staple fiber). It is defined as the weight in grams of 9,000 meters of fiber or yarn. Carpet yarn ranges between 1000 to 4200 denier, tire cord is typically between 840 to 1260 denier, upholstery yarn between 70 to 3200 denier, and yarn for apparel ranges between 15 to 140 denier.

** Some spinning machines have a filter before the distribution plate whereas others have a filter before each spinneret; also, there may be more than one spinneret per site depending on mechanical design.

revolving faster than the up-line roll. The fiber is then heat treated to reduce shrinkage and wound onto tubes at a speed as high as 3800 yards per minute. This speed is always slower than the draw speed in order to "relax" the fiber. A "spin finish" is applied before drawing, but after spinning and quenching, to lubricate the fiber and minimize abrasion and static electricity.

Since spinning is a continuous process, in the sense that fiber is being continually extruded, it should be recognized that more than one spool (package*) is consecutively wound from a running threadline. When a package reaches the desired size the thread line is cut and intercepted (by a vacuum hose) and the fully wound package is removed and replaced by an empty tube to be wound with more fiber. A simplified schematic of a spinning machine site for nylon fiber production (monofilament and yarn) is shown in Exhibit 2824-4.

Nylon staple fiber production differs from nylon monofilament and yarn production in that after the fibers are melt-spun and quenched (the same as for monofilament and yarn production), they are combined from the various quenching ducts into tow, drawn and cut, pneumatically conveyed to a hot air chamber and then press baled. A schematic is shown in Exhibit 2824-5.

Nylon 6

Nylon 6 fiber is commonly produced by the water-catalyzed polymerization of caprolactam. As with nylon 6,6, nylon 6 can be made by

* In industry, a spool of wound fiber from a spinning machine is referred to as a "package".

either a batch or continuous process. Since the batch process is currently uneconomical, most of the nylon 6 and monofilament produced is by the continuous process for polymer chip. The nylon 6 polymer chip is preferred over the directly spun polymer because unpolymerized monomer and oligomer may be removed more effectively from the chip by a hot water wash, than by high-vacuum evaporation of the molten polymer in the "direct spinning" process. This differing level of impurity will adversely affect yarn quality and tenacity. The production of nylon 6 staple and tow is commonly performed by the continuous polymerization process for direct spinning, which uses the high vacuum evaporation step since staple and tow product quality are not nearly as sensitive to impurity (monomer and oligomer) concentration as yarn and monofilament.

Caprolactam, with various additives (antioxidant, ultra-violet light stabilizer, titanium dioxide, etc.) is polymerized (Exhibit 2824-6) - continuously in a reactor containing approximately three internal tubular heat exchangers. The heat exchangers control polymerization temperature and assist in creating a uniform flow pattern; they are Dowtherm® heated. Water by-product is removed from the upper portion of the reactor. A screw pump extrudes polymer from the bottom of the reactor through a die plate thereby forming polymer strands. The strands pass through a water bath, quenching (hardening) them, and then to a chopper where they are pelletized. Water from the quencher is recirculated and cooled. The next step, chip washing, is done by contacting the polymer chips with a countercurrent stream of hot water; monomers and oligomers are extracted and the hot water wash is recycled (with some make-up water from the quencher). Most of the water is then removed on a dewatering screen and then in centrifuge. Any residual moisture is removed by drying with a

countercurrent stream of hot nitrogen. The moisture is removed from the nitrogen and is recycled. The finished nylon 6 chip is conveyed to a storage silo for later use. (The entire process is carried out under an inert (nitrogen) atmosphere).

Yarn production from nylon 6 chip is similar to that from nylon 6,6 chip; the difference is that, in the case of nylon 6, the fiber is spun and drawn on two separate machines. The spun only yarn is referred to as "partially oriented yarn" (POY). Drawing, twisting, and texturing may be done later on another machine. This process requires more product handling but a one step spindrawing process would not be economical without high speed windups (spinning machine productivity would be greatly reduced). Recent developments have made combined spindrawing of nylon 6 fiber possible but are not typical of the industry.

Staple and tow nylon 6 are made from the continuous polymerization of caprolactam into molten polymer for direct spinning use. The polymerizer is similar to that used for the production of nylon 6 chip. The difference is a thin-film evaporator, following the reactor, for the removal of water laden with monomer and oligomer (for recycle). The polymer melt is pumped directly to the spinning machine where nylon 6 staple fiber is produced in the same way as nylon 6,6 staple fiber.

A schematic outlining in sequence the process steps for the production of yarn + monofilament and staple + tow of nylon 6,6 and nylon 6 polymer is shown in Exhibit 2824-7.

2.0 NATIONAL DATA

The annual national data for nylon fiber production are presented in this section. A summary of energy consumption and production is shown in Exhibit 2824-8.

2.1 Capacity and Production Data

Summarized below is the total U.S. production of nylon fiber and all non-cellulosic fiber for 1973 through 1977.

U.S. Production[1]

(millions of pounds)

	1973	1974	1975	1976	1977
Nylon Fiber					
Yarn + monofilament	1583	1560	1295	1373	1512
Staple + tow	592	564	562	703	814
Total Nylon Fiber	2175	2124	1857	2076	2326
Non-Cellulosic Fiber					
Yarn + monofilament	3340	3443	3209	3305	3668
Staple + tow	2970	2781	2677	3320	3654
Total Non-Cellulosic Fiber	6310	6224	5886	6625	7322

Total U.S. capacity for nylon fibers in 1977 and an estimate for 1978 is shown below.

U.S. Capacity[2]

(millions of pounds/year)

	1977	1978*
Nylon Fiber		
Yarn + monofilament	1,901	2,104
Staple + tow	959	1,080
Total	2,860	3,184

* Estimated

There are 39 nylon fiber producing plants in the U.S.[2] held by 27 companies[3]. The following companies contributed to a total nylon fiber capacity of 2,643 million pounds in 1976.

1976 Nylon Fiber Capacity by Company
(Millions of pounds/year)

Akzona (American Enka)	240
Allied Chemical	230
Celanese	90
Courtaulds	5
Dow Badische	150
DuPont	1,100
El Paso (Beaunit)	80
Firestone	45
Monsanto	450
Rohm and Haas	50
Standard Oil of Calif. (Fibers Intl.)	63
Wellman	40
others	100
Total	2,643

Plant capacities for all nylon fiber (6,6 and 6) range between 5 to 400 MMlbs/yr with a typical plant capacity for nylon 6,6 and 6 at 120 MMlbs/yr and 100 MMlbs/yr, respectively.

2.2 Annual Energy Consumption

The U.S. Census Bureau reports the following energy consumption by fuel type for SIC 2824 in 1975[4]:

1975 Annual Energy Consumption, SIC 2824

Energy Source	Consumption (x 10^{12} Btu)
Fuel Oil	43.15
Coal	35.91
Natural Gas	19.76
Other*	4.59
Purchased Fuel (Total)	103.41
Purchased Electricity**	21.16
Purchased Fuels and Electric Energy (Grand Total)	124.57

* "Other" includes "Fuels not specified by kind"[4].

** Purchased Electricity converted at 3413 Btu/kWh; self-generated electricity is already included in the individual fuel consumptions above in order to avoid double counting.

The total annual energy consumption for nylon 6,6 and nylon 6 fiber can be estimated as the product of annual production and the typical overall energy requirement per ton of product. Based on the data presented in section 3.1, the typical overall energy requirement, including offsites and taking into account that the batch and continuous process each contribute equally to nylon 6,6 production, is estimated below:[5]

Unit Energy Consumption (MMBtu/ton)

	Yarn + Monofilament	Staple + Tow
Nylon 6,6		
Total	9.92	13.91
Fuel	5.77	6.61
Electricity	4.15	7.30
Nylon 6		
Total	16.73	9.95
Fuel	2.72	4.14
Electricity	14.01	5.81

Since a certain amount of electric energy is commonly generated on-plant, this factor had to be considered in order to accurately assess the total purchased fuels and total purchased electric energy. The 1975 Census of Manufactures for SIC 2824 estimates that approximately 12.2% of the total electric energy consumed is self-generated. Applying this proportion against the total electric energy consumed in nylon fiber production, on-sites plus off-sites, and by adding its equivalent fuel value, at 30% generation efficiency, to the total fuel consumption for nylon fiber, the annual energy consumption for 1975 is estimated below:

1975 Annual Energy Consumption, Nylon Fiber

Energy Source	Consumption (x 10^{12} Btu)
Fuel Oil*	3.11
Coal*	2.59
Natural Gas*	1.42
Other*	0.33
Purchased Fuel (Total)	7.45
Purchased Electricity**	5.72
Purchased Fuel and Electric Energy (Grand Total)	13.17

* Total purchased fuel was distributed across the various fuel types proportionately with the 1975 Census of Manufactures fuel data.

** Converted at 3413 Btu/kWh.

3.0 PROCESS ENERGY REQUIREMENTS

The following sub-sections describe the thermal and electrical energy requirements per unit of production in nylon fiber manufacture. A summary of the energy requirements per unit output is presented in Exhibit 2824-9.

3.1 Unit Energy Consumption Data

Nylon fiber production is an energy intensive operation requiring a diversity of process steps, each with different characteristics of energy consumption. For each of the process steps shown in Exhibit 2824-7, the following energy requirements are considered typical[5].

Unit Energy Requirements
(MMBtu/ton)

Nylon 6,6

	Nylon Salt Production	Polymerization (Batch)	Polymerization (Continuous)	Chip Formation	Screw Melting	Spinning (Yarn)	Spinning (Staple)
Fuel**	1.81	4.17	3.58	0.16	Negligible	Negligible	0.84
Electricity	0.15	0.06	0.04	0.23	2.98	2.35	5.50
Total	1.96	4.23	3.62	0.39	2.98	2.35	6.34

Nylon 6

	Polymerization (plus Chip Formation)	Polymerization (Direct Melt)	Screw Melting	Spinning (POY* + Drawing)	Spinning (Staple)
Fuel**	2.72	3.30	Negligible	Negligible	0.84
Electricity	1.18	0.31	2.98	9.85	5.50
Total	3.90	3.61	2.98	9.85	6.34

* POY - Partially Oriented Yarn.
** Fuel is used to generate steam and heat Dowtherm®.

To find the total energy used by a process the above energy requirements can be summed by process step as sequenced in Exhibit 2824-7. For example, nylon 6,6 yarn production for the batch process requires 11.91 MMBtu/ton total, while the continuous process requires 7.93 MMBtu/ton total. Since the batch and continuous process contribute equally to nylon 6,6 production, the overall energy requirement combined for both processes is 9.92 MMBtu/ton.

3.2 Details of Energy Consumption

Nylon fiber production is continuous, and plants operate 24 hours per day, 7 days per week, all year. Shutdowns are usually not scheduled unless a drop in polymer quality indicates need for a clean-up. In the nylon 6,6 continuous polymerizer, two separators, finishers, and pumps are usually installed in parallel thus allowing for convenient switchover and clean-up without process interruption. Local overheating in polymer lines may cause gel (degraded polymer) to form and dramatically decrease spinning machine performance (increase filament/ yarn breaks, decrease polymer quality); in such a case, a shut down may be warranted.

The production of nylon 6,6 salt requires mostly steam with little electrical energy. Steam derived heat is used to dissolve monomer in methanol, by jacketing the monomer mix tanks, and for recovering monomer and methanol from the centrifuge residue in an evaporator. Electricity is used to drive the centrifuge, agitators, and pumps.

From the polymerizer to the spinneret, high temperatures are needed for reaction and to reach the optimum spinning temperature range, as high as 290-295°C for nylon 6,6 and 280-285°C for nylon 6. Although

energy consumption may vary from one type of polymerizer to another, Dowtherm * is predominantly used as the heating medium to attain these temperatures. Dowtherm is usually heated in a boiler (like steam) by natural gas. Low pressure steam (50-60 psig), usually let down from plant steam (typically at 250-300 psig), is used in the evaporator. In polymerizers, steam is likely to be used only before the reactor since Dowtherm is necessary to attain the required high temperatures in and following the reactor.

In the chip formation and screw melting process steps, following nylon 6,6 batch polymerization, the use of Dowtherm® is small and steam use is negligible. In the screw-melting of polymer chip, heat transfer is accomplished by a combination of electrical heating and mechanical energy. Electrical energy is used to remelt the polymer chip because it provides a finer control over the remelting operation than Dowtherm® . Polymer chip is melted in stages across grids, each carefully controlled to prevent polymer degradation, and then transported molten by a screw conveyor, also heated electrically.

Steam use in nylon 6 polymerization processes is primarily for creating a hot water wash or a vacuum (through venturi jets) both to be used for monomer extraction in the chip forming or direct melt processes, respectively. (Hot water is also used to heat the monomer storage tanks.) Dowtherm® is used to jacket the reactor (and thin-film evaporator in the direct-melt process) and all polymer lines prior to extrusion.

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* Dowtherm® , as a heat transfer medium, is more stable than oil at higher temperatures, less viscous at lower temperatures and has the added advantage that it can be employed as a vapor, for its latent heat of condensation as well as its sensible heat(6). Dowtherm is a trademark of the Dow Chemical Company.

The final use of Dowtherm®, in most processes, is in jacketing the polymer transfer lines or spinnerets prior to extrusion or spinning.

Spinning is considered to be more of an art than a technology; spinning machines are highly varied from company to company, and highly proprietary. Although the typical unit energy requirements reported in Section 3.1 show primarily electric energy consumptiom with negligible steam use, differences in utility consumption are known exist depending on design. For instance, in the heating step prior to wind-up, hot air may be derived from a steam heat exchanger rather than an electric heater, or both may be used.

4.0 ANTICIPATED TRENDS

This section discusses trends through the year 2000. Major emphasis is on market development and trends in process technology and energy consumption.

4.1 Product Growth Trends

U.S. nylon fiber production in 1977 represented 32%[1] of all U.S. non-cellulosic synthetic fiber.

Nylon fiber has a variety of end uses in products such as carpets, apparel, tire cord, upholstery, and other industrial products. The percent end use of all U.S. nylon fiber consumed in 1976 is shown below.

U.S. Nylon Fiber Consumption By End Use, 1976[1]

	All U.S. Nylon Fiber			
	Yarn + Monofilament %	Staple + Tow %	Total %	Estimated Share of Nylon 6[5] %
Carpet	27	30	57	50
Apparel	23	2	25	20
Tire Cord	13	--	13	20
All Other	4	1	5	10
Total	67	33	100	100

Demand for nylon fiber from 1977 through 1985 and 2000 is estimated below and on Exhibit 2824-10.

Demand for Nylon Fiber
(Billions of Pounds)

	Historical[2]	Forecast	
	1977*	1985[7]	2000
All Nylon Fiber	2.32	3.43	7.13 ± 20%
Yarn + Monofilament	1.51	2.05	na
Staple + Tow	0.81	1.38	na

* 1977 data is production data; for the purpose of this table, production is assumed to be equal to demand.

From 1977 to 1985 an overall growth rate for all nylon fiber is estimated at 5.0% per year. Contributing to this are yarn + monofilament and staple + tow at growth rates of 4.0% and 7.0% per year and market shares of 67% and 33%, respectively.[7] Long range demand estimates to the year 2000 are difficult to predict with a product such as nylon. Historically, ever since its invention in 1937, markets have been created for nylon fiber (parachutes, tire cord, carpets, apparel, textured upholstery, etc) hence, demand has varied greatly. For such a product an accurate growth rate to 2000, including the possibility of new markets being created, would be difficult to estimate. Another factor affecting nylon fiber growth is the impact of world oil supplies on its raw material price, since nylon raw materials are petroleum-based. However, assuming that factors such as population growth affecting apparel and purchase of new and used homes affecting carpet and home furnishing textiles are in play, an estimated 5% per year growth rate for all nylon fiber with a tolerance of ± 20% , to the year 2000, may be expected.

A favorable factor to note is that, while nylon is 32% of the non-cellulosic synthetic fiber production (SIC 2824) it consumes only 10% of the energy for the entire SIC. High production levels and continuous production processes account for the low energy consumption, thus allowing for lower costs per unit volume (or weight) than other SIC 2824 fibers (except perhaps for polyester, whose costs are comparable to nylon).

Process capacity in 1977 and 1980 for nylon fiber (yarn + monfilament and staple + tow) is shown below.

	Nylon Fiber			
	Capacity (MMlbs/yr)[7]		Capacity Utilization (%)	
	1977	1980	1977	1980*
All Nylon Fiber	2,860	3,080	81	87
Yarn + Monofilament	1,901	2,085	80	82
Staple + Tow	959	995	85	100

* Based on estimate of production at 5% per year growth rate for all nylon fiber and 4.0% and 7.0% per year for yarn + monofilament and staple + tow, respectively.

4.2 Process Changes and Implementation of New Technology

Nylon fiber production requires many process steps, as shown in Exhibit 2824-7. Although all of these require careful control, the steps most critically controlled and most sensitive to polymer quality are the polymerization and spinning steps. Technological advances in these process steps are highly proprietary and well guarded. However, there have been numerous recent advances in continuous polymerization and spinning machine technology.[5]

In the continuous polymerizer, polymer quality is sensitive to the rate of by-product water removal, reactor residence time, temperature and pressure, polymer handling (screw conveyors, uniform Dowtherm® heat transfer in polymer lines, etc), and additives. A new reactor design, differing dramatically from the tubular reactor, is expected to contribute significantly to nylon production. This new reactor uses its own by-product water vapor with other gases (for example, HMDA) to preheat the feed before entry into the reactor. Using a thermal gradient, reactor feed is circulated and recirculated until the desired polymer density is reached. The polymer of desired density (or viscosity) is removed from the circulating and polymerizing reactor feed by movement through two juxtaposed separating baffles within the reactor. This process is expected to consume less energy than the tubular reactor process and offers the advantage of attaining the desired polymer quality considered more difficult to achieve consistently with other polymerizer types.

Since the spinning machine typically limits the production rate, implementation of technology to increase production, as well as product quality, are expected to emerge where economically justified. Increased implementation of the spindrawing process (spinning and drawing combined into one continuous operation on one spinning machine) will undoubtedly increase as a function of capital availability. In combination, these spin-drawing machines are designed to wind more packages per spinning position, thereby increasing capacity and decreasing energy consumption per unit output. It should be noted that with present overcapacity, the implementation of more spindrawing processes, with increased capacity, may not be economically justified for some time to come.

Another market development, a result of new technology, is the invention of a new nylon fiber which reduces static and soiling in carpeting. The new product, "Ultron" nylon by Monsanto, utilizes fibers of trilobal cross section, to hide soil, in combination with round bicomponent nylon fibers containing an electrically conductive carbon plus nylon stripe.

In addition, a new and large market for nylon fiber was created. A nylon reinforced rubber boom system for the containment and skimming of oil from spills will be used by off-shore oil drilling companies. The system has several distinct advantages over other systems, better chemical resistance and design.

4.3 Trends in Energy Requirements

In developing an energy conservation target for the Department of Energy for SIC 28, an energy conservation target for SIC 2824 of 19.8% for 1980, relative to 1972 energy consumption levels was estimated.[8] For nylon fiber production, a specific energy conservation target was also estimated at 17.1%.[8]

Based on this target, it was assumed that such a reduction in unit energy consumption could be achieved by 1985, relative to 1975, and that an additional reduction of 15-20%, with an average of 17%, in unit energy consumption between 1985 and 2000 is feasible.

The total estimated energy consumption, including a breakdown showing fuel and electric energy consumed, through the year 2000, is presented below.

Estimated Energy Consumption Trends, 1975-1985-2000

Nylon Fiber Production

$X\ 10^{12}$ Btu	1975	1985	2000
Total Purchased Fuel and Electricity	13.17	20.13	33.27± 20%
Purchased Fuel	7.45	11.39	18.82± 20%
Purchased Electricity*	5.72	8.74	14.45)± 20%

* at 3413 Btu/kWh.

Since fuel consumption by type in this industry is not expected to change substantially through the year 2000, the following fuel breakdown, proportionate with the 1975 Census of Manufactures, is estimated for the years 1985 and 2000.

Estimated Fuel Consumption by Type, 1975-1985-2000

Nylon Fiber Production

$X\ 10^{12}$ Btu	Purchased Fuel	Coal	Oil	Gas	Other
1975	7.45	2.59	3.11	1.42	0.33
1985	11.39	3.96	4.75	2.18	0.50
2000(±20%)	18.82	6.54	7.85	3.60	0.83

5.0 PLANT SPECIFIC DATA

This section provides available data relating to specific plant energy requirements, load profiles, state conditions, and reliability considerations. Several plant factors are summarized in Exhibit 2824-11.

5.1 Load Profiles

Nylon fiber plants operate continuously; 24 hours/day, 7 days/week, all year. Although a batch process like batch polymerization may yield product at finite intervals, it is in operation as often as is necessary in order to maintain a continuous supply of polymer to the spinning machines. Other polymerizers operate continuously. However, is should be realized that a plant usually contains more than one polymerizer feeding more than one spinning machine (typically feeding one to two spinning machines, depending on the denier produced). In many plants it may be economical to shutdown a process line, with respective spinning machines, if product demand is not expected to follow production rate for an extended period of time. This precise strategy explains the currently low overall capacity utilization of 81%.

Since plant operation is continuous, with few process line shutdowns, a load factor is estimated at approximated 90%; likewise, thermal/-electrical coincidence factors are estimated to be in the range of 0.90 to 1.0.

5.2 Energy Flow, Mass Flow and State Conditions

As outlined in Exhibit 2824-7 and described in Section 1.2, nylon fiber production consists of many process steps, from raw material to finished product. The energy consumed by each of these steps with a discussion of how and where it is used can be found in Section 3.1 and 3.2.

As noted in Section 5.1, nylon fiber plants usually consist of more than one polymerizer feeding more than one spinning machine. Typical continuous polymerizers have capacities ranging from 30 to 35 million pounds per year.[5] Plants with a significantly smaller capacity probably utilize the batch polymerizer process. (However, batch polymerizers are also built to similar capacities as continuous polymerizers.) Approximate overall mass flows for the various process reaction steps are shown below[5]:

<u>Nylon 6,6</u>

<u>Nylon Salt Production</u>

HMDA		Adipic Acid		Water		50% Nylon 6,6 Salt Solution		Unreacted HMDA Recovered with Methanol
0.46 lb	+	0.56 lb	+	1.00 lb	⟶	2.0 lb	+	0.02 lb

<u>Polymerization</u>

50% Nylon Salt Solution				Nylon 6,6 Polymer		Water
2.0 lb	+	additives	⟶	1.0 lb	+	1.0 lb

<u>Nylon 6</u>

<u>Polymerization</u>

Caprolactam				Nylon Polymer		Monomer Recovered and Recycled
1.1 lb	+	additives	⟶	1.0 lb	+	0.10

The spinning machines process 100% of the polymer produced. Typical outputs include 90% finished product and 10% waste although, during product type change overs, as much as 70% of a day's production will be dispositioned as waste.

For the nylon 6,6 and nylon 6 processes, state conditions are tabulated below:

Nylon 6,6 and Nylon 6
Process State Conditions

Nylon 6,6 Salt Production

	HMDA Mix Tank	Adipic Acid Mix Tank	Reactor
Temperature (°C)	35	40	60
Pressure (psig)	0	0	0

Nylon 6,6 Polymerization

Batch Process	Evaporator	Reactor (five stages; see Section 1.2) one	two	three	four	five (discharge, extrude, and chop)
Temperature (°C)	150	150-230	250	270	270-275	270-275
Pressure (psig)	25	250	250	0	0	0
Time (minutes)	30	10-30	50-60	40-90	20-30	30

Continuous Process	Evaporator	Reactor	Flasher	Separator	Finisher	Spinneret
Temperature (°C)	125	210-250	280	280	285-290*	290-295
Pressure (psig)	0	210-250	0	0	-5 to -10	--
Dowtherm® (°C)	--	235-285	285	282	280/275**	291-296

* Finisher outlet temperatures ranges between 285 to 290 °C; inlet temperature ranges between 280 to 285°C.

** Finisher is Dowtherm® vapor jacketed at 280°C with the exception of the screw conveyor which is liquid Dowtherm® cooled at 275°C.

Nylon 6 Polymerization

Polymer Chip Process	Feed and Mix Tank	Reactor	Chip Washing Column	Drying Column
Temperature (°C)	70-80	260-265	40 polymer chip 90-100 water wash	90 polymer chip 180 nitrogen gas
Pressure (psig)	na	na	na	na

Direct Melt	Feed and Mix Tank	Reactor	Evaporator	Spinneret
Temperature (°C)	70-80	260-265	270-280	280 285
Pressure (psig)	na	na	na	--

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5.3 Reliability Considerations

Nylon fiber production is carefully controlled because product quality is extremely sensitive to any change in process operating conditions.

In the polymerizer, any loss of power will deteriorate polymer quality and consequently, spinning machine performance (i.e., increased fiber breaks). A power outage of less than ten minutes will not seriously affect polymer quality, but will definitely upset all connected spinning machines (i.e. "knock down" all spinning positions). Power outages of an extended period of time will cause polymer degradation (gel and carbon formation), partial polymerization, and complete hardening of polymer in process lines, thus freezing all pumps and screw conveyors.

The spinning machine is especially sensitive to a power loss. A power loss of more than a tenth of a second will result in an immediate upset of all spinning positions.[5] Similarly, any variance in power would destroy fiber quality thereby dispositioning it as waste.

Polymerizer residence times vary between approximately 4 and 15 hours, for nylon 6,6 and nylon 6, respectively, thus contributing significantly to the time lost in production. In addition the total time lost would also include repair, start-up, and product testing feedback. Estimated downtime, excluding the duration of the power failure, is from one to four days.[5]

EXHIBIT 2824-1

NYLON SALT PRODUCTION

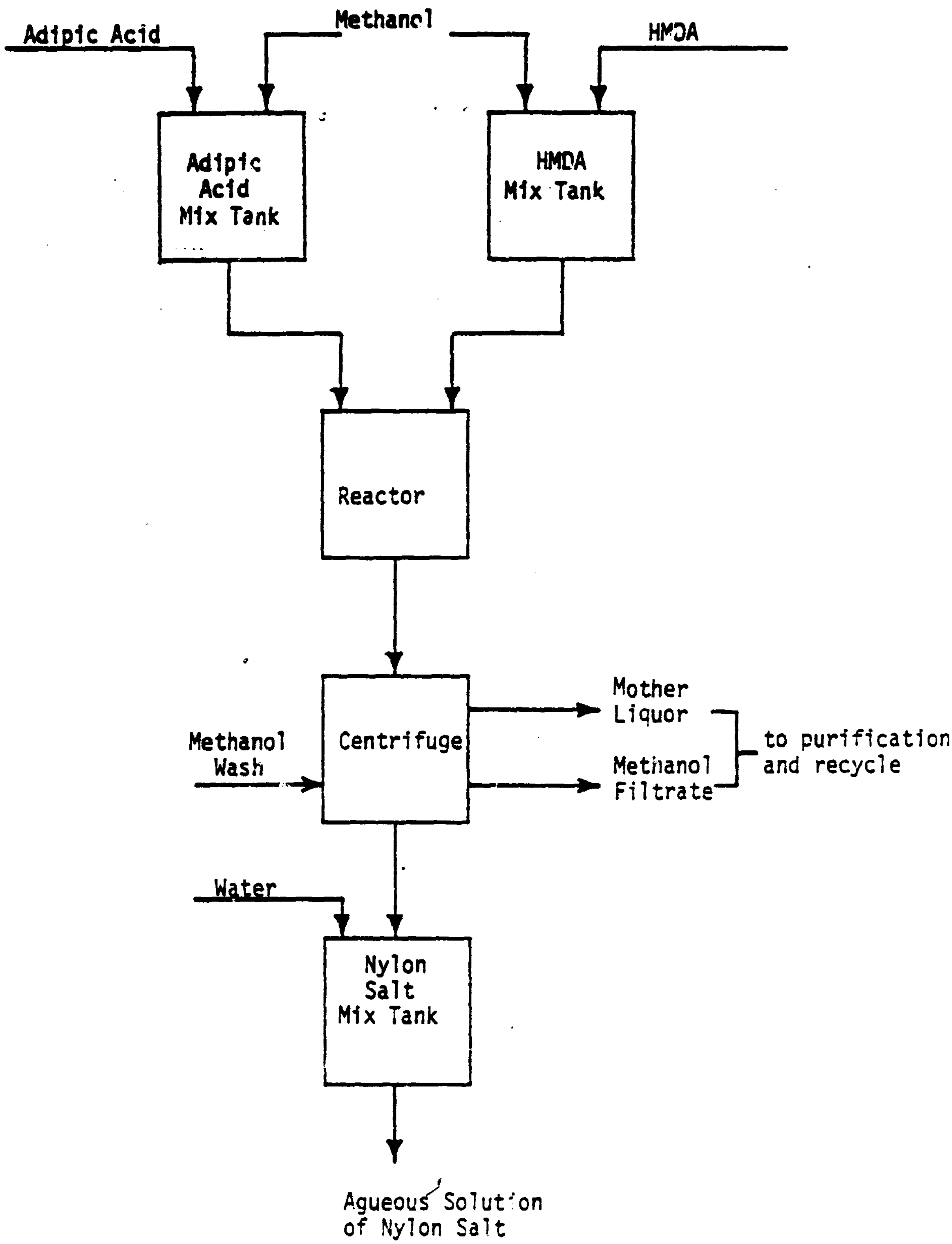


EXHIBIT 2824-2

NYLON 6,6 - BATCH POLYMIZERATION PROCESS

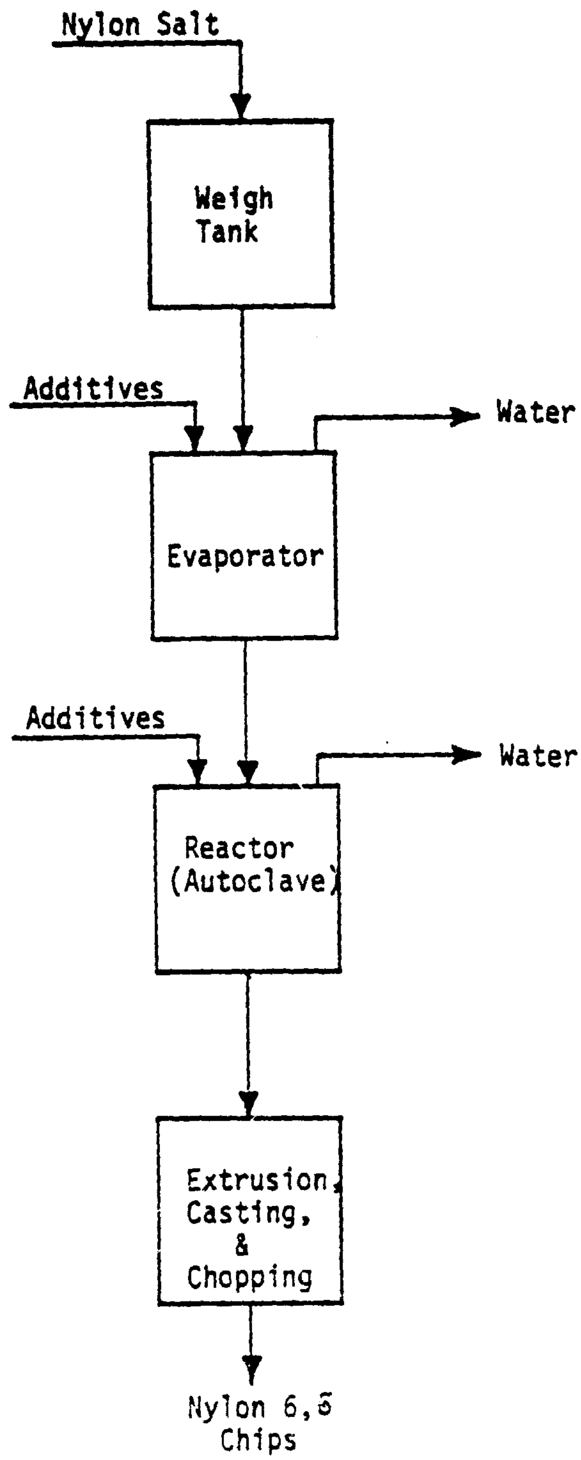
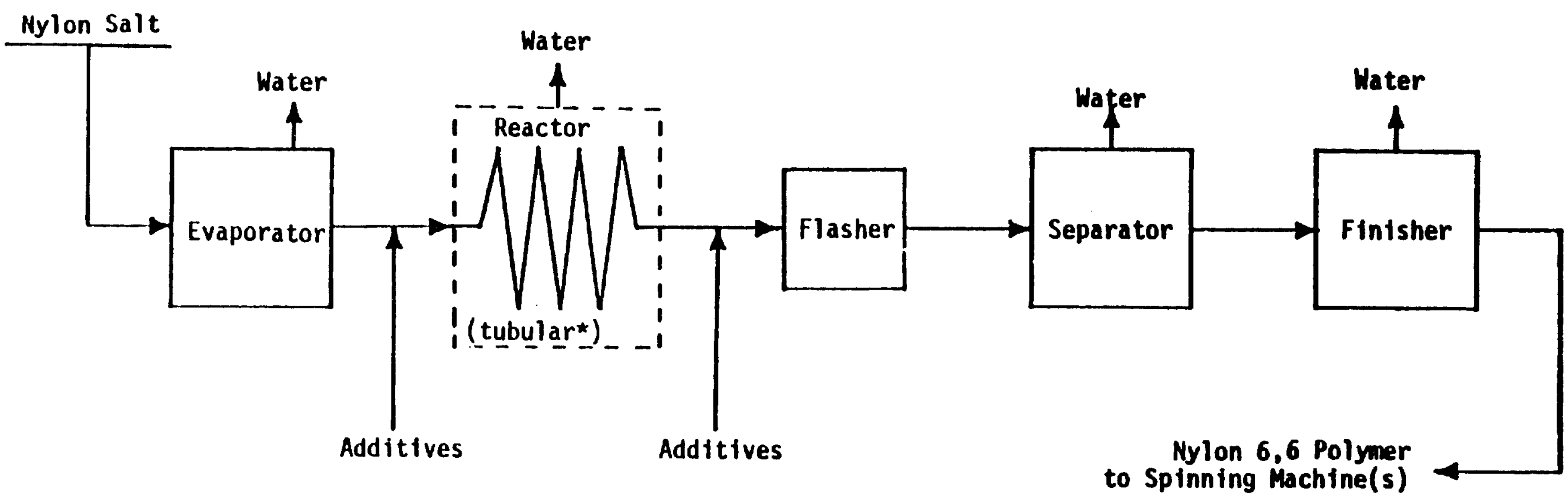


EXHIBIT 2824-3

NYLON 6,6 - TUBULAR REACTOR, CONTINUOUS POLYMERIZATION PROCESS



* Tubular reactors vary in size from 200 to 300 feet in length and 12 to 19 inches in inside diameter.

EXHIBIT 2824-4

NYLON 6,6 FIBER SPINNING

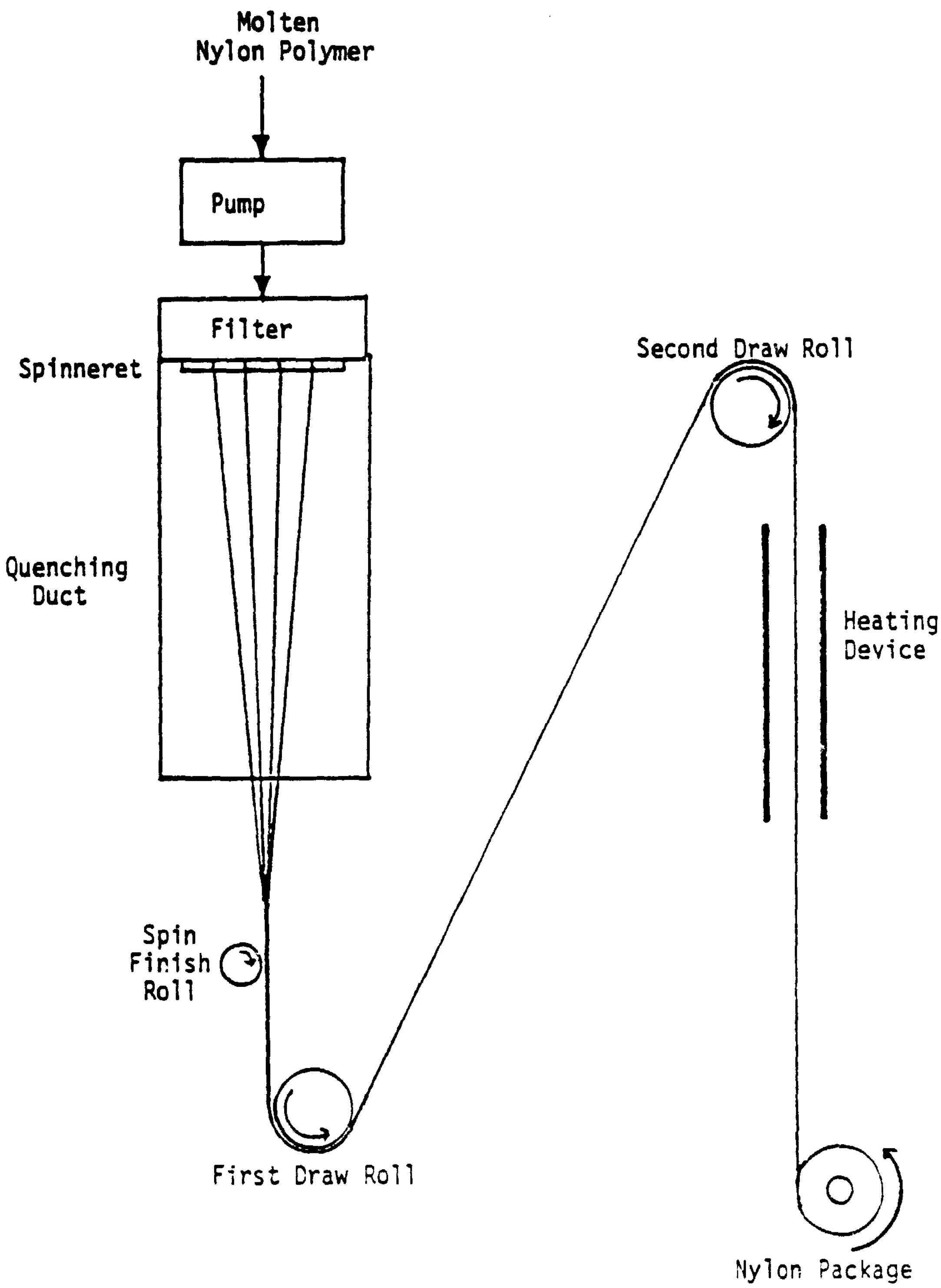


EXHIBIT 2824-5

NYLON 6,6 -STAPLE PRODUCTION

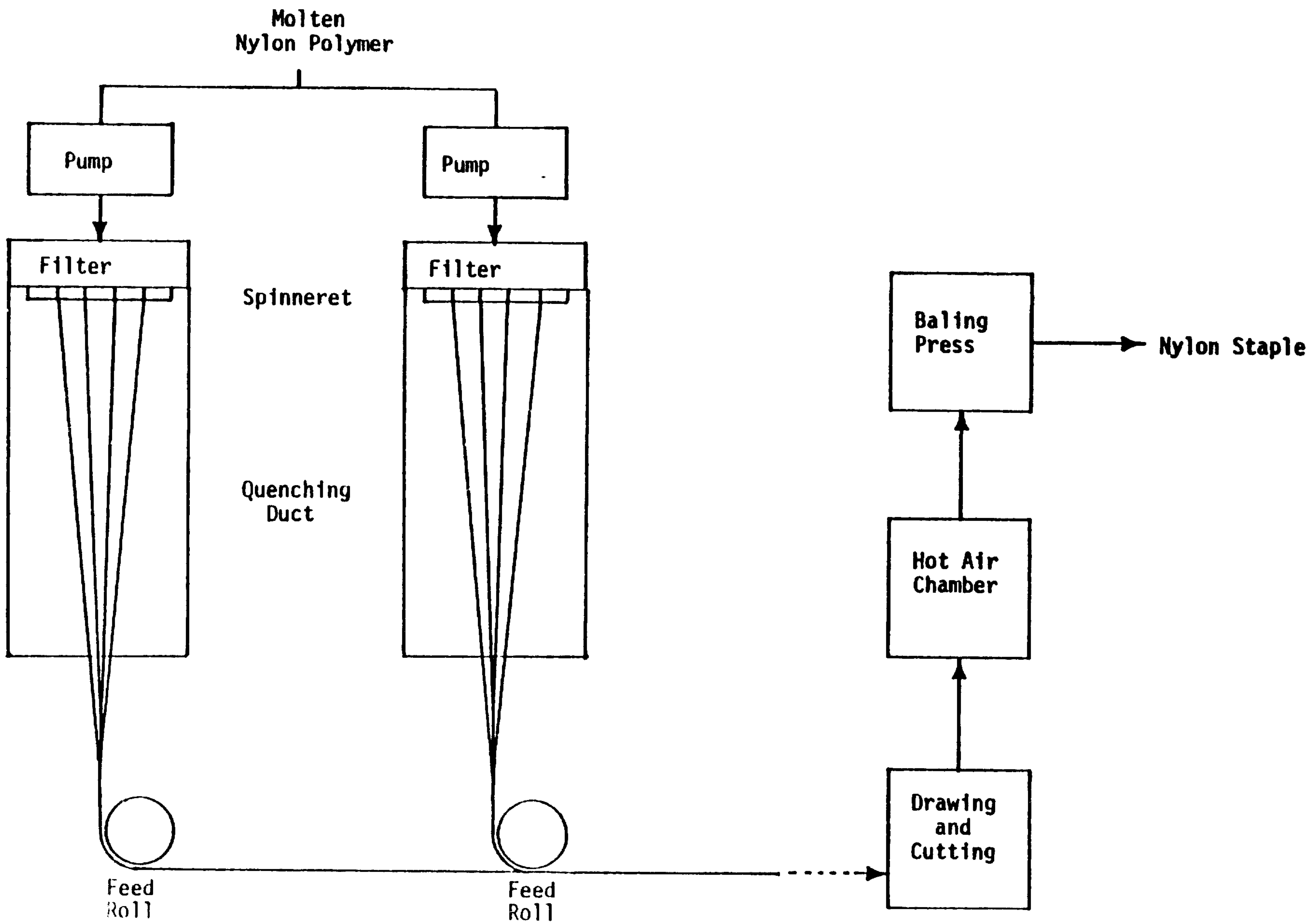


EXHIBIT 2824-6

NYLON 6 - POLYMERIZATION FOR CHIP

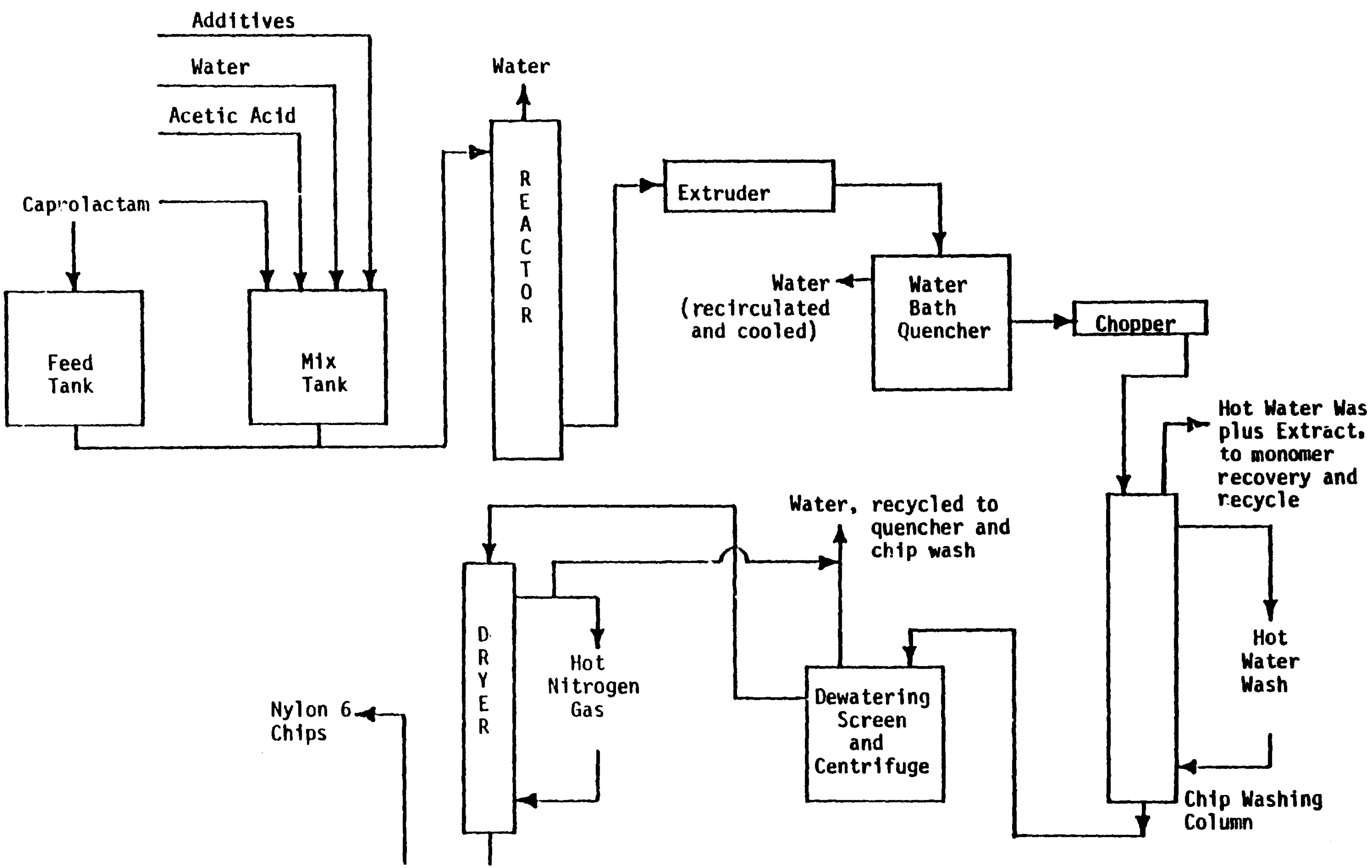
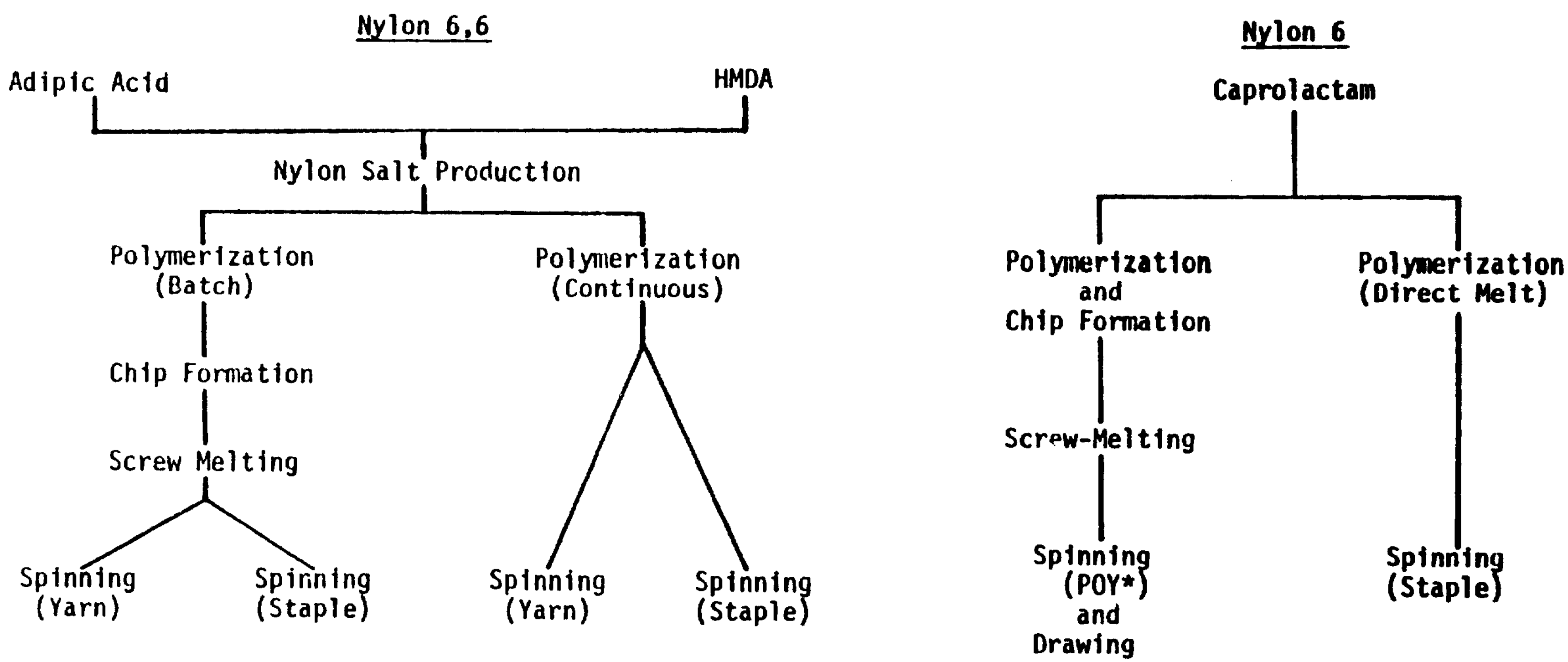


EXHIBIT 2824-7

NYLON 6,6 AND NYLON 6 FIBER, PROCESS SUMMARY



* POY - Partially Oriented Yarn

EXHIBIT 2824-8

ANNUAL NATIONAL DATA (1975), SIC 2024 - NYLON FIBER

	Product* Production Million Ton	Total Energy Consumption Trillion Btu	Purchased*** Electricity Trillion Btu	Purchased** Fuels Trillion Btu	Coal**	Oil**	Gas**	Other**	Total Energy Consumption For SIC Trillion Btu	Percent Total Energy Consumption Represented
Nylon 6,6 - Total	0.65	8.20	2.92	5.28	--	--	--	--	--	--
Yarn + Monofilament	0.45	5.00	1.64	3.36	--	--	--	--	--	--
Staple + Tow	0.20	3.20	1.28	1.92	--	--	--	--	--	--
Nylon 6 - Total	0.28	4.97	2.80	2.17	--	--	--	--	--	--
Yarn + Monofilament	0.19	3.93	2.34	1.59	--	--	--	--	--	--
Staple + Tow	0.09	1.04	0.46	0.58	--	--	--	--	--	--
Total, Nylon 6,6 and Nylon 6	0.93	13.17	5.72	7.45	2.59	3.11	1.42	0.33	124.57	10.57%

* Nylon 6,6 and Nylon 6 fiber production are estimated proportionate with their share of total nylon fiber production (70% and 30%, respectively)(6); the breakdown into yarn + monofilament and staple + tow for nylon 6,6 and nylon 6 separately, are also estimated by applying the same percentages (70% and 30%, respectively) to each of the total yarn + monofilament and staple + tow categories.

** Total purchased fuel was distributed across the various fuel types proportionately with the 1975 Census of Manufactures fuel data.

*** Electric energy converted at 3413 Btu/kWh

EXHIBIT 2824-9

ENERGY CONSUMPTION PER UNIT OUTPUT: NYLON FIBER PRODUCTION

	Electricity* Million Btu Per Ton	Hot Water Million Btu Per Ton	Steam (Million Btu Per Ton)			Direct Fuel** Million Btu Per Ton	Exhaust Steam	
			To 300°F	300-500°F	Over 500°F		Temperature °F	Energy Million Btu Per Ton
Nylon 6,6								
Yarn + Monofilament	4.15	--	0.52	1.45		3.32	--	--
Staple + Tow	7.30	--	0.52	2.12	--	3.32	--	--
Nylon 6								
Yarn + Monofilament	14.01	--	--	1.30	--	1.09	--	--
Staple + Tow	5.81	--	--	1.13	--	2.73	--	--

* at 3413 Btu/kWh

** Natural gas for the firing of Dowtherm boilers.

EXHIBIT 2824-10

DEMAND FOR NYLON FIBER

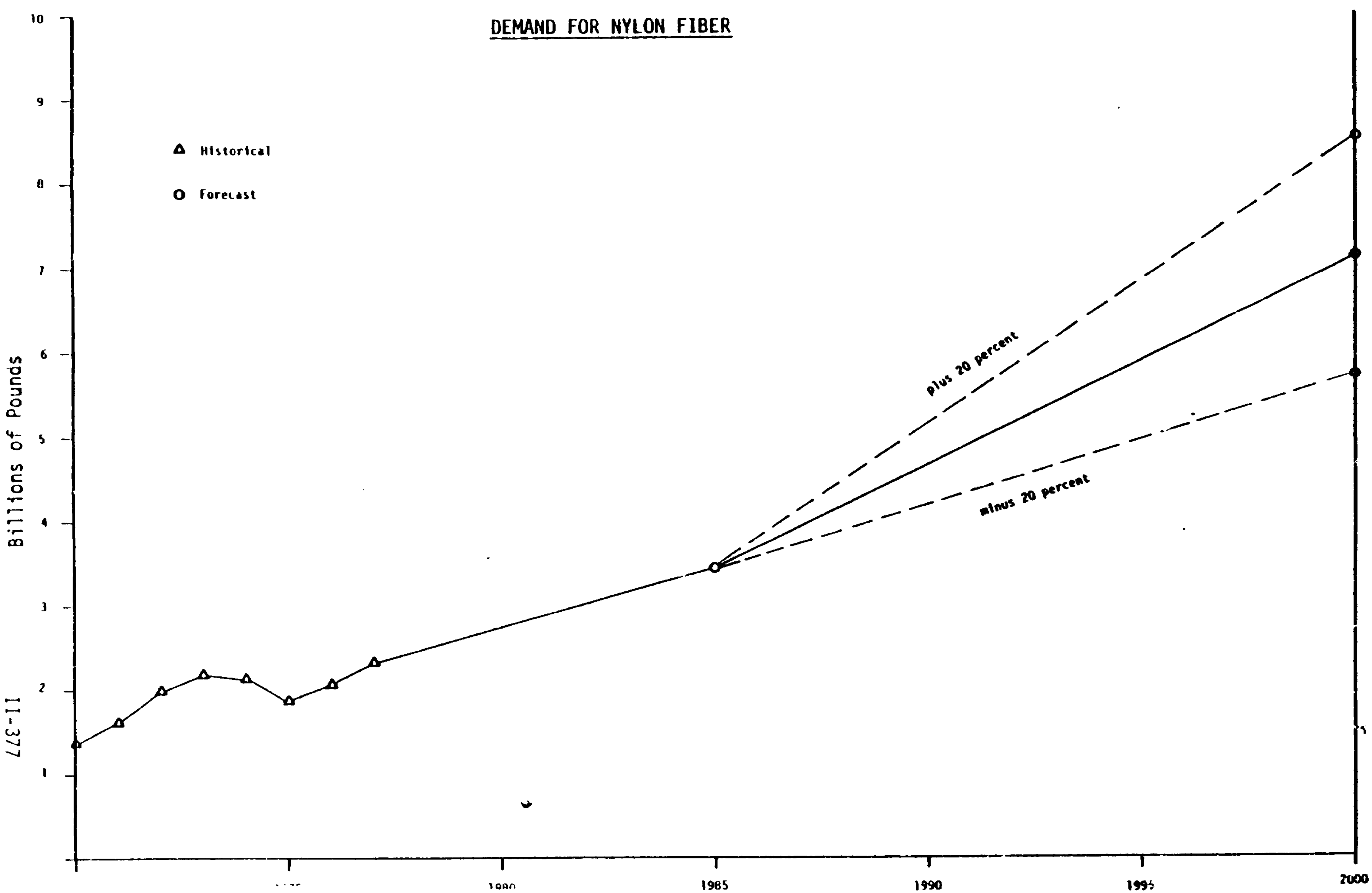


EXHIBIT 2824-11

NYLON FIBER PLANT FACTORS

Typical Plant Capacity Tons/Year	Plant Size Range Tons/Year	Electric Load Factor	Thermal Electrical Coincidence Factor	Projected Applicability To 2000 Tons/Year
57,000	2,500 - 200,000	90%	0.90 - 1.0	Good

FOOTNOTES

(1) "Textile Organon", Textile Economics Bureau Inc., New York, Vol. 49, No. 2, February 1978.

(2) "Textile Organon", Textile Economics Bureau, Inc., New York, Vol 48, No. 6, June 1977.

(3) Man-Made Fibers Fact Book, Man-Made Fibers Producers Association, Inc., Washington, D.C. 1978.

(4) U.S. Department of Commerce, Bureau of Census "Annual Survey of Manufactures, Fuels and Electric Energy Consumed", 1975.

(5) Private communication with industry representatives.

(6) Shreve R.N., Chemical Process Industries, fourth edition, McGraw-Hill, New York, 1977.

(7) "Will Oil Companies Damage U.S. Chemical Markets?", European Chemical News, IPC Industrial Press, London, Vol 31, No. 812, November 18, 1977, pp.-27.

(8) Battelle Columbus Laboratories, "Developing a Maximum Energy Efficiency Improvement Target for SIC 28", Federal Energy Administration, July 1976.

STYRENE PRODUCTION

1.0 PROCESS IDENTIFICATION

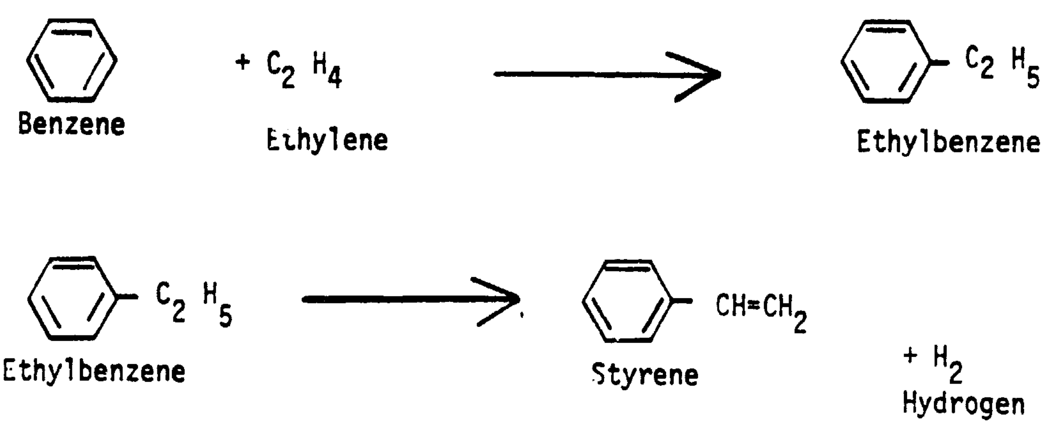
This section identifies and specifically defines the industry, and provides a brief description of the current production processes employed.

1.1 SIC Classification

The production of styrene is classified under SIC code 2865, which covers "establishments primarily engaged in manufacturing coal tar crudes and cyclic organic intermediates, dyes, color lakes and toners." There are over 80 chemicals classified under SIC 2865, including (in addition to styrene) aniline, benzoic acid, cychlohexane, hydroquinone, isocyanates, phenol, phthalic anhydride, and various dyes and colors.

1.2 Process Description

Styrene in the U.S. is presently produced by the catalytic dehydrogenation of ethylbenzene which, in turn, is most often produced by the catalytic alkylation of benzene with ethylene (some 5-10% is extracted from C_8 aromatics). The reactions for producing ethylbenzene and styrene are summarized below:



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Both processes are discussed separately below, although it is normal practice to integrate the two processes together. Simplified process diagrams are included as Exhibits 2865-1 and 2865-2.

Ethylbenzene Production: There are two major process used in the production of ethylbenzene. One route involves addition of the catalyst, $AlCl_3$ (Aluminum Chloride), at the reactor, while the other process uses fixed beds of BF_3 (Boron Trifluoride) as the catalyst. The separation sections of both processes are very similar. By far, most of the ethylbenzene is produced by using $AlCl_3$. Thus, this process is described in detail below.

Benzene is dried by distillation and pumped continuously into a stirred reactor vessel. Aluminum chloride catalyst is introduced via a continuous mechanical feeder and ethylene is sparged into the bottom of the vessel. A small amount of catalyst promotor, such as ethyl chloride, is usually added to increase catalyst activity. The reaction proceeds at a temperature of 200-205°F and a reactor pressure of around 5 psig. A commercial installation generally involves several reactors operating in parallel. Benzene is maintained in excess in the reactor in order to ensure complete reaction of ethylene. In practice, 99% reaction of ethylene is normally achieved, and as a result there is very little gas purged from the reactor.

The reactor effluent is a mixture of ethylbenzene, catalyst, unconverted benzene and byproducts such as diethylbenzene. The crude alkylate is cooled and settled to separate out the catalyst which is partly recycled to the reactor and partly pumped to the dealkylator. The hydrocarbon stream from

the settlers is washed with caustic soda solution and water to remove traces of aluminum chloride and acid and then routed to surge tank. Material from the surge tank is then fed up to the fractionation section for separation and purification of ethylbenzene.

Ethylbenzene fractionation involves three major towers. The crude ethylbenzene is first distilled to remove the heavy tars and polyethyl benzenes and then distilled again to remove lighter boiling benzene which is recycled to the reactor. The ethylbenzene is finally distilled a third time to remove remaining diethyl benzene which is recycled to the reactor. The tars and polyethyl benzenes removed in the first tower are mixed with some of the catalyst withdrawn from the crude alkylate settlers, and heated to around 400°F in the dealkylator reactor. The purpose of this step is to decompose these heavier boiling materials to yield additional mono and diethyl benzene which can be recycled for separation and recovery. The effluent from the dealkylation reactor is tar, contaminated with aluminum chloride.

Styrene Production: Ethylbenzene dehydrogenation is carried out at high temperature and low pressure. A low ethylbenzene partial pressure is achieved by using a steam diluent in the reactor. A steam to ethylbenzene molar ratio of 15:1 is typical.

Ethylbenzene feedstock is mixed with a small proportion (around 10%) of the total steam to be used in the reaction section, preheated and then introduced into the reactor at approximately 960°F. The balance of the steam is superheated to 1300°F and introduced into the reactor. This technique permits reactor heat to be supplied without passing the ethylbenzene through the furnace, which would cause fouling and coking

difficulties. The reactor operates at an outlet temperature of 1050 - 1100°F and a pressure of 10 psig or less. The reactor contains a fixed catalyst bed, which usually consists mainly of iron oxide with potassium oxide and chromium oxide promoters.

The reactor effluent contains styrene, uncoverted ethylbenzene and small amounts of by-products. A once-through conversion to styrene of 40-60% is achieved. The gas stream is cooled by heat exchange with feedstock ethylbenzene and steam, and then quenched by direct contact with water at approximately 200°F. The hydrocarbon/water mixture is separated into a settling drum. Crude styrene is pumped to intermediate storage while the water phase is partly recycled to the quench condenser and partly steam stripped to remove traces of aromatics and then purged from the process. Byproduct condensate may be suitable for use as boiler feed water after suitable treatment. The gases produced in the dehydrogenation reactor consist primarily of hydrogen with smaller amounts of methane, ethylene and carbon dioxide. These are vented as non-condensibles from the quench condenser and usually used as fuel.

Crude styrene is purified by fractionation. Several different distillation sequences are used, but the following is typical. Crude styrene is distilled to remove light ends (mainly benzene and toluene) and then routed to a very large superfractionator to split ethylbenzene from styrene. This is a difficult separation as the boiling point difference between the two key components is only 16°F. The tower distillate is ethylbenzene, which is recycled to the reactor section.

The tower bottoms is pure styrene except for small amounts of heavy ends which are removed in a final rerun tower.

Careful temperature control of the styrene distillation section is vital. It is important that styrene should not be heated to greater than 210°F. Above this temperature, styrene polymerization is induced at a rate that would rapidly plug equipment with polymer. The fractionation section is operated under vacuum, therefore, as the boiling point of styrene at atmospheric pressure is 293°F.

The styrene/ethylbenzene splitter and styrene rerun towers generally operate at pressures of 50mm mercury absolute or less. In addition, a polymerization inhibitor such as sulphur or dinitrophenol is introduced into the crude styrene to further reduce polymerization, and tower reboiler temperature differentials are maintained as low as possible by the use of low pressure steam. Use of these techniques controls styrene polymerization losses to 0.7% or less. Finished product styrene is inhibited with a phenolic antioxidant to prevent oxidation and polymerization in tankage.

2.0 NATIONAL DATA

The annual national data presented in this section are summarized in Exhibit 2865-3. The derivation and significance of the production and energy consumption data are discussed in the following sub-sections.

2.1 Capacity and Production Data

Total U.S. styrene production capacity as of January 1978 was 4.61 million tons annually, while ethylbenzene capacity was 5.54 million tons per annum. Exhibit 2865-4 presents a breakdown of U.S. styrene and ethylbezene capacity by plant and producer. The plants tend to be concentrated in Louisiana and Texas, and ethylbenzene and styrene plants are usually co-situated.

Production of styrene was 3.41 million tons in 1977, ranking it as the 19th largest volume chemical for that year. Production of ethylbenzene, which ranked 18th among the largest volume chemicals, was 3.65 million tons in 1977[1].

There are 12 corporations in the U.S. currently producing styrene. Plant sizes range from 40,000 tons/year to 750,000 tons/year. New plants tend to be toward the upper end of the plant size range, for example the new Oxirane plant recently completed near Houston has a nameplate capacity of 500,000 tons per year.[2] The average of the plant sizes in Exhibit 2865-4 is about 300,000 tons/year.

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1 "Chemical and Engineering News", May 1, 1978, p.33.

2 "Chemical and Engineering News", Aug. 15, 1977, p. 10.

2.2 Annual Energy Consumption

The U.S. Census Bureau reports the following consumption of energy in 1975 for SIC code 2865[1].

1975 ENERGY CONSUMPTION, SIC 2865

ENERGY SOURCE	CONSUMPTION
Fuel Oil	35.99×10^{12} BTU
Coal	12.59×10^{12} BTU
Natural Gas	96.25×10^{12} BTU
Purchased Electricity	4.5×10^{9} KWH

As explained in section 1.1, styrene and ethylbenzene are not the only products classified under SIC 2865. The total energy consumption for these products in 1975 can be obtained by multiplication of the unit energy consumption data (see section 3.1) by the annual production for 1975.

If steam generation is assumed to be 80% efficient, and the breakdown of purchased fuel by type is in the same ratio as for the entire 4-digit SIC code, the following estimate of 1975 energy consumption for the manufacture of styrene and ethylbenzene results:

1975 ENERGY CONSUMPTION FOR STYRENE PRODUCTION

ENERGY SOURCE	CONSUMPTION
Fuel Oil	21.32×10^{12} BTU
Coal	7.50×10^{12} BTU
Natural Gas	57.10×10^{12} BTU
Purchased Electricity	0.18×10^{9} KWH

1. U.S. Dept. of Commerce, "Annual Survey of Manufactures", Fuels and Electric Energy Consumed, 1975 edition.

The production of styrene and ethylbenzene intermediate represents about 54% of the energy consumed by SIC 2865, on a total (purchased electricity and purchased fuel) BTU basis[1].

1 Electricity converted at 3413 BTU KWH

3.0 PROCESS ENERGY REQUIREMENTS

The sub-sections which follow describe in depth the energy consumed per unit production in ethylbenzene/styrene manufacture, as well as providing detail on the type of energy required. A summary of the energy requirements per unit output appears in Exhibit 2865-5.

3.1 Unit Energy Consumption Data

The production of ethylbenzene/styrene consumes energy in the form of steam, natural gas and electric energy. The unit energy consumption data presented in this section of the report are based on the production of ethylbenzene from ethylene and benzene via the $AlCl_3$ catalyst route, and the production of styrene from ethylbenzene via the traditional catalytic dehydrogenation route.

A unit of production for the purpose of this report is defined as one ton of styrene in the case of styrene production from ethylbenzene and 1.15 tons of ethylbenzene in the case of production of ethylbenzene from ethylene and benzene (since 1.15 tons of ethylbenzene are required to produce one ton of styrene). Thus the total energy to produce one ton of styrene is composed of the energy to produce 1.15 tons of ethylbenzene plus one ton of styrene.

The production of styrene is rather thermal energy intensive. Steam (50 psig) supplies most of the thermal energy requirements. Electrical energy requirements are very low, with only 259,000 BTU of electrical energy required per ton of styrene compared to 31,280,000 BTU of thermal energy.

The styrene production portion of the process consumes some 82% of the total energy, while the ethylbenzene portion of the process consumes the other 18%. This is due in part to the endothermic nature of the dehydrogenation reaction. Exhibit 2865-5 represents the energy consumption data per unit of output, by type of energy, broken down between the ethylbenzene and styrene portions of the process.

3.2 Details of Electricity Consumption

The production of styrene is a continuous process, with load factors in excess of 90%. Typically, a styrene unit will be capable of run lengths as long as two years. Electrical energy is used to power pumps and compressors, with electricity generally purchased from an outside utility.

The process does not normally include any very large compressors. Therefore high peak loads when commissioning individual drivers are unlikely to be a problem.

3.3 Details of Thermal Energy Consumption

The thermal energy requirements are supplied by steam. Natural gas is used to superheat steam for the dehydrogenation reaction; none of the direct process heat is supplied by the gas however.

The steam pressure generally used in styrene producing facilities (exclusive of steam from the superheaters) is about 50 psig, although Monsanto reports the use of 75 psig steam in their plants.[1]

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1 "Hydrocarbon Processing", November 1977, p.227.

The bulk of the steam used (about 94%) for ethylbenzene production is in the separation section (see Exhibit 2865-1). The bulk of the steam use for styrene production is for the dehydrogenation reaction section (73%). The dehydrogenation reaction is endothermic, with a heat of reaction of about 750 BTU/lb. The other 27% of the energy is used in the separation portion of the styrene plant.

The superheater, which uses natural gas, and the hydrogen purge stream from the dehydrogenation reactor (see below), emits a high temperature stack gas. The stack gas is at 500°F and represents a heat rejection equivalent to 720,000 BTU per ton of styrene produced.[1]

Some steam is exhausted from the cooling section, after the dehydrogenation reactor in the styrene plant. This steam is at 440°F and has an energy content equivalent to 1.96 million BTU per ton of styrene produced.[1] The energy content of this stream is used elsewhere in the plant.

Considerable quantities of hydrogen are produced in the dehydrogenation reactor. As a general rule, one mole of hydrogen is produced per mole of ethylbenzene fed to the reactor, although this is somewhat conservative as side reactions may tend to increase the hydrogen make. On this basis some 2.9 million BTU (fuel value) of hydrogen are produced per ton of styrene manufactured. This hydrogen is combined with an additional 2.0 million BTU/ton of natural gas for combustion in the superheater. The purge gas is essentially sulfur free. Typical purge gas quality is:

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1 Dow Chemical Company, "Energy Consumption: The Chemical Industry", EPA contract, EPA 650/2-75-032, April 1975, p.27.

Component	Mole Percent
Hydrogen	85
Carbon dioxide	8
Ethylene	2
Methane	3
Carbon Monoxide	0.1
Water and other Hydrocarbons	balance

One final waste stream of interest is the tars produced in the separation section of the ethylbenzene plant. These tars have a fuel value equivalent to 200,000 BTU per ton of styrene produced, but are heavily contaminated with the $AlCl_3$ catalyst, and are therefore discarded at present.

4.0 ANTICIPATED TRENDS

This section discusses the trends which are likely to occur in the industry through the year 2000. The major emphasis is on three areas: marketing, process technology, and energy consumption.

4.1 Product Growth Trends

Ethylbenzene and styrene ranked 18th and 19th, respectively in volume of shipments of industrial chemicals in the U.S. during 1977[1]. As mentioned in section 2[illegible], production of styrene was 3.41 million tons in 1977, while production of ethylbenzene was 3.65 million tons in 1977. Currently about 99% of the ethylbenzene produced is used in the production of styrene. The other 1% is used as a solvent. It is expected that styrene production will remain the single important use for ethylbenzene. Thus, future ethylbenzene production will be directly dependent on future production of styrene.

The end use pattern for styrene in the U.S. is as follows:[2]

Use	% of Production
High impact, modified polystyrenes	28.0
Polystyrene	22.0
Styrene-butadiene rubber	8.7
Acrylonitrile-butadiene-styrene	7.9
Styrene-butadiene resins	5.3
Unsaturated polyesters	5.7
Styrene-acrylonitrile resins	1.2
Exported	15.0
Other	6.2
	100.0

1 "Chemical and Engineering News", May 1, 1978, p.33.

2 "Chemical Marketing Reporter", November 7, 1977, p.9.

Annual growth in styrene production is approximately half as rapid as the growth rates a decade ago.[1] Polystyrene has become a mature plastic, hence its future growth will be less rapid than in the past. The only outlet for styrene which has the potential for double-digit annual growth are the unsaturated polyesters.

A considerable quantity of styrene is currently exported from the U.S. This quantity is expected to slowly decline as the world economy improves.

Overall it is estimated that styrene production will grow at 6% per annum until 1980, and then at 5% per annum until 1985[2].

In the longer term (1985-2000) growth in styrene production is expected to more limited, as end-use products reach maturity. An annual growth rate of 3% would be reasonable in this time period, given no severe business dislocations, and ample supply of ethylene and benzene at competitive prices.

Exhibit 2865-5 shows the historical and projected production of styrene in the U.S. By comparison with Exhibit 2865-4, it is seen that the industry is currently operating at about 74% of capacity. Capacity appears to be adequate until the mid-1980's.

4.2 Process Changes

Several process alternatives to conventional ethylbenzene dehydrogenation are available. Two of the most promising of these alternatives are outlined below:

---

1 "Chemical and Engineering News", August 15, 1977, page 9-10.

2 "Chemical Age", April 15, 1977, page 13.

The first alternative is the so called hydroperoxide process. This process involves the oxidation of ethylbenzene at 285°F and 10 psig, by air. The partially oxidized ethylbenzene is allowed to react with an excess of propylene in the presence of a catalyst at 230°F and 575 psig. This reaction yields propylene oxide and methylphenyl carbinol which is in turn dehydrated at 500°F over TiO_2 catalyst to yield styrene. Styrene is purified via distillation.

This process is believed to be the process used in the new 500,000 ton per year plant currently undergoing start-up by Oxirane Corp. in Texas. The process features somewhat reduced utilities consumption (estimated at 12.4 million Btu/ton of steam, 2.0 million Btu/ton of natural gas, and 0.56 million Btu/ton of electric energy), and the economics of the process depend in part on the ability of the producer to sell the propylene oxide.

The second process depends on the conversion of toluene to stilbene by lead oxide at 1100°F. The stilbene is purified and reacted with ethylene over TiO_2 catalyst at about 900°F. The styrene product is then separated and purified. This process does not require ethylbenzene production.

This process (being developed by Monsanto) claims greatly reduced utilities (5.5. million Btu/ton of steam, 2.5 million Btu/ton of natural gas and about 0.14 million Btu/ton of electric energy) but is unproven and unlikely to be available before 1990.

4.3 Implementation of New Technology

As previously noted in section 4.1 of this report, the industry currently operates at about 74% of capacity. With the current start-up of the Oxirane Unit, new capacity will not be required until after 1982.

If the Oxirane plant proves successful, and the market for propylene oxide holds up, much of the new capacity expected to be brought on in the period 1982-1990 could be by the hydroperoxide process. Should Monsanto be successful in developing the Stilbene process on a commercial scale, this process could capture a portion of the capacity in 1990-2000 period. The extent of its implementation, will depend on the capital required for construction, and the relative costs of raw materials for this process.

4.4 Trends in Energy Requirements

The FEA "Target" for SIC 2865 is a 18.4% reduction in unit energy consumption by 1980 relative to 1972 energy consumption levels.[1] The target was derived largely on a qualitative basis and is composed of reductions of 5-6% of the base energy due to improved housekeeping, 6-8% of the base energy through engineering improvements, and the rest of the 18.4% due to process changes.

Assuming that a 18% reduction in energy use relative to present energy consumption levels could be achieved by 1985, and that the hydroperoxide process will account for 50% of the new capacity required to meet demand by that date, Exhibit 2865-7 estimates total national energy consumption in 1985 for styrene production.

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1 "Maximum Energy Efficiency Improvement Target For SIC 28" Battelle Columbus Laboratories, March 4, 1977.

If it is assumed that 50% of the post-1985 capacity will use the hydroperoxide process, 15% the stilbene process and 35% the conventional dehydrogenation reaction process, the energy consumption for 2000 can be predicted. Styrene produced by the conventional process, and all ethylbenzene production is assumed to be at 1985 efficiency (18% improvement over current efficiency). Production in 2000 is as per Exhibit 2865-6. Given these assumptions, energy use for styrene production in the year 2000 is estimated in Exhibit 2865-7.

While it is not possible to predict the mix of fuels likely to be consumed in the year 2000 (other than the breakdown between purchased fuels and electricity shown in Exhibit 2865-7), it is expected that fuel gas will continue to be required to fire superheaters. Thus, the 1975 fuel mix can be assumed to be applicable to 1985 and 2000.

5.0 PLANT-SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements, including indications of load profiles, state conditions, and reliability considerations. Several plant factors are summarized in Exhibit 2865-8.

5.1 Load Profiles

Styrene plants generally operate at nearly constant rates for 24 hours a day, 7 days a week. Run lengths up to 2 years have been reported. Electrical energy is used to power pumps and compressors. Therefore, load factors around or above 0.9 can be expected.

Due to the continuous nature of the process, the need for steam coincides with the electrical requirements. Hence, Exhibit 2865-8 indicates a thermal-electrical coincidence factor of 1.0.

5.2 Energy Flow Schematics

Simplified energy flow schematics for ethylbenzene and styrene production appear in Exhibits 2865-9 and 2865-10 respectively. Energy requirements in Exhibit 2865-9 relate to 1.15 tons of ethylbenzene produciton, while energy requirements in Exhibit 2865-10 related to one ton of styrene production. These energy requirements are illustrative of current energy consumption levels.

5.3 State Conditions and Mass Flows

As previously mentioned in section 3.3, steam use in ethylbenzene/styrene plants (exclusive of steam from the superheaters) is generally at 50

psig. This pressure (and thus the steam temperature) may vary somewhat dependent on the individual licensor/contractor. As can be seen from Exhibit 2865-10, the major use of steam is in the reaction section of the styrene portion of the plant.

Mass flows, for styrene and ethylbenzene production, are listed below:

1) Ethylbenzene Production

Material	Units Per 1.15 Tons Ethylbenzene
Benzene	0.889 tons
Ethylene	0.317 tons
$AlCl_3$	0.008 tons

2) Styrene Via Dehydrogenation Of Ethylbenzene

Material	Units Per Ton of Styrene
Ethylbenzene	1.15 tons
Process Water	2.0 gallons
Inhibitor	0.16 tons

Typical feedstock specifications are shown below:[1]

Ethylene

Mol %	99.5
Principal impurities % Max.	0.2
Water & Methanol ppm Max.	20

Benzene

Distillation range °F Max (including 176.2°F)	1.8
Freezing Point (dry) °F Min	9.54
Toluene wt % Max.	0.05
Non-Aromatics wt % Max	0.1

1 Monsanto's Styrene Process, "Oil and Gas Journal", March 12, 1973, p.89.

5.4 Reliability Considerations

Styrene production is a continuous, steady-state process in which flow rates, temperatures, pressures and levels are generally in balance at all times. A high degree of routine or continuous monitoring of conditions, using sophisticated instruments, is employed to assist in maintaining the balance. The loss of any utility supply immediately upsets the process balance. Loss of water to coolers and condensers results in pressure rise and venting of hydrocarbons to atmosphere or a safety system. Loss of electric power can upset the instrument controls and stop a large number of pumps with various undesirable consequences. If any of the consequences cause loss of flow through furnace tubes or reactors, tube failures can result and catalyst beds may be ruined. Although a multitude of safety devices are incorporated into the design to ensure safe venting and orderly shutdowns, a risk of fire and/or explosion is always present. For these reasons, producers take every action possible to ensure that utility supplies are dependable and particular emphasis is paid to electric power.

With respect to forced outage, it would be desireable for the cogeneration device planned maintenance to coincide with the 2 year maintenance cycle for styrene plants.

EXHIBIT 2865-1

ETHYLBENZENE PRODUCTION

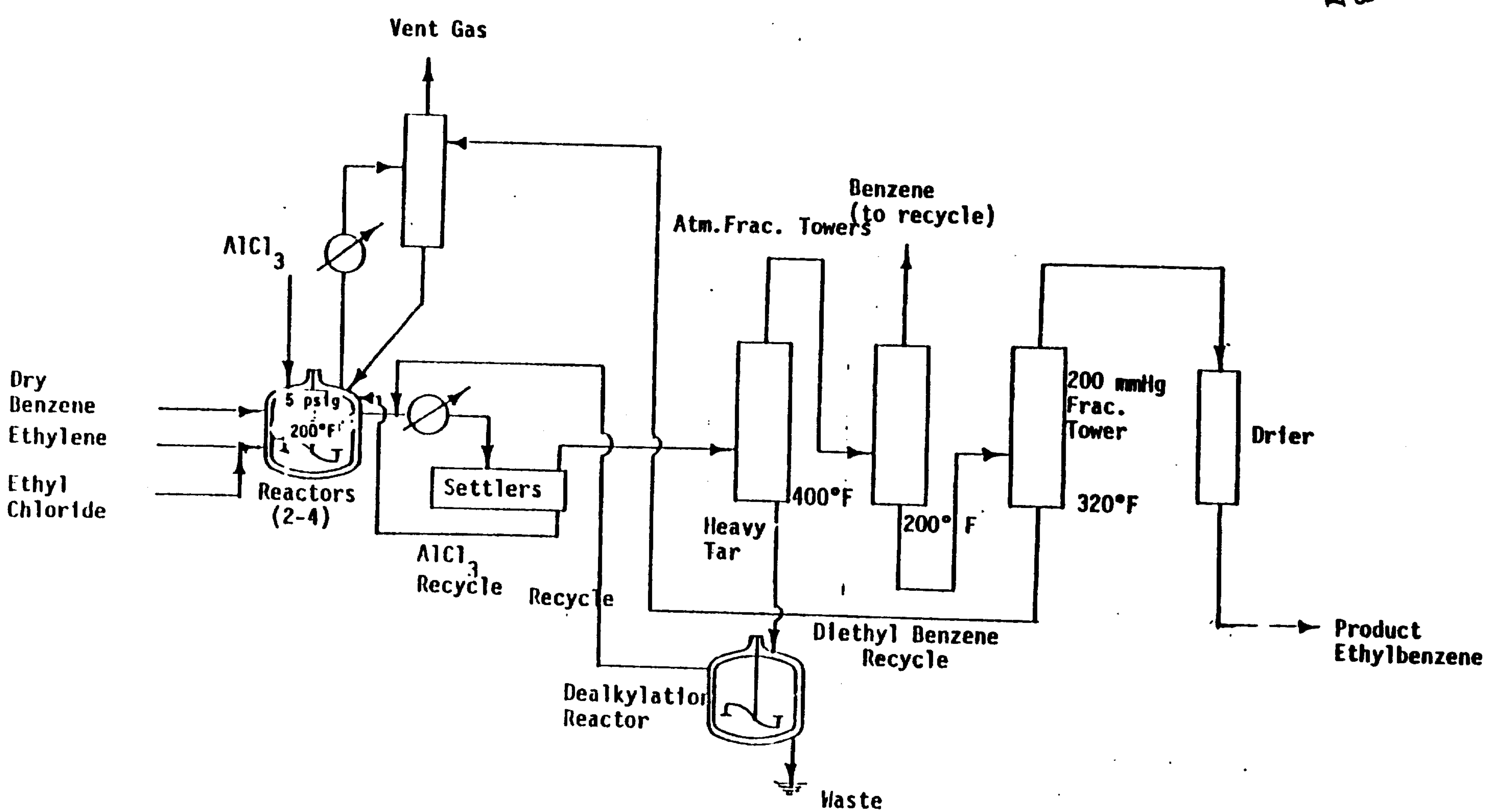


EXHIBIT 2865-2

STYRENE PRODUCTION

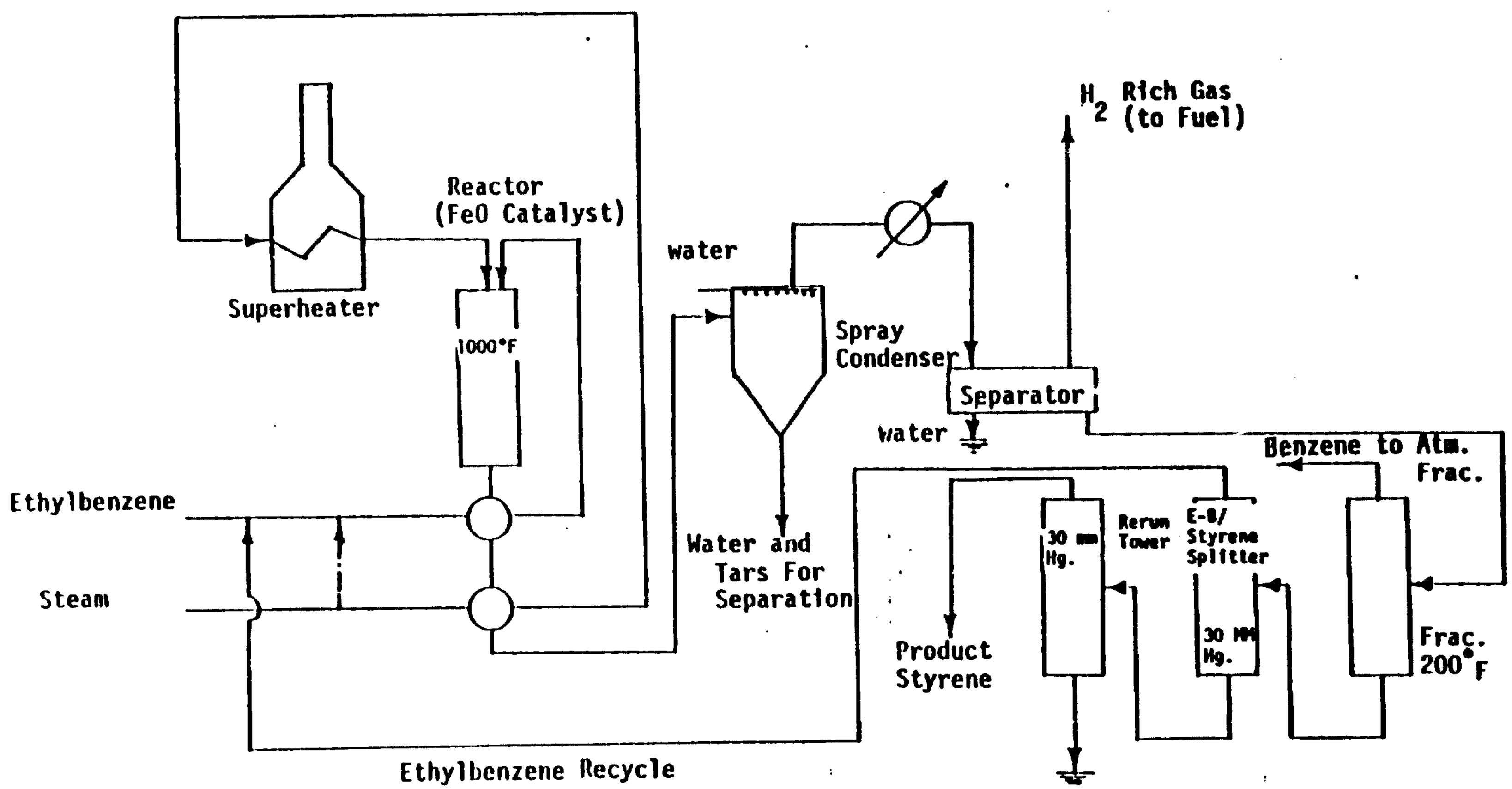


EXHIBIT 2865-3

ANNUAL NATIONAL DATA (1975) STYRENE PRODUCTION *

Product Production-Million Tons	Total Energy Consumption Trillion Btu	Purchased Electricity-Trillion Btu	Purchased Fuels Trillion Btu	Coal	Oil	Gas	Other	Total Energy Consumption For SIC Trillion Btu	Percent Total Energy Consumption Represented
2.34	90.96**	0.61**	90.35	7.50	21.32	57.10	4.43	167.58	54.3

* Includes production of Ethylbenzene intermediate from benzene and ethylene.

** Purchased electricity converted to Btu at 3413 Btu/Kwh.

Note:

Breakdown of purchased fuels into coal, oil gas and other is in the same proportion as the 1975 Census data for SIC 2865. The percentage of purchased fuel represented by coal may actually be smaller for styrene than other products in the 4-digit SIC code.

EXHIBIT 2865-4

U.S. ETHYLBENZENE AND STYRENE CAPACITY[1]

(Thousands of tons)

OPERATOR (LOCATION)		ETHYLBENZENE	STYRENE
Amoco Chemicals	(Texas City, Tx.)	490	420
Arco Polymers	(Beaver Valley,Pa.)	-	220
Arco Polymers	(Houston, Tx.)	68	60
Arco Polymers	(Port Arthur,Tx.)	250	-
Charter Chemical	(Houston,Tx.)	20	-
Cosdan	(Big Spring, Tx.)	42	44
Cos-Mar	(Carville, Tx.)	760	650
Dow Chemical	(Freeport, Tx.)	860	750
Dow Chemical	(Midland, Mich.)	275	200
El Paso Products	(Odessa, Tx.)	135	75
Foster Grant	(Baton Rouge, La.)	580	495
Gulf	(Donaldsonville, La.)	300	260
Monsanto	(Texas City, Tx.)	850	750
Oxirane	(Channelview, Tx.)	575	500
Styrochem	(Penuelas, P.R.)	80	-
Sun	(Corpus Christ, Tx.)	65	40
Tenneco	(Chalmette, La.)	18	-
Union Carbide	(Seadrift, Tx.)	170	150
	TOTAL	5538	4614

1. As of Jan. 1978

SOURCES: Chemical Marketing Reporter, Stanford Research Institute, Chemical and Engineering News.

EXHIBIT 2865-5

ENERGY CONSUMPTION PER UNIT OUTPUT* IN ETHYLBENZENE/ STYRENE PRODUCTION

Product	Electricity** Million Btu Per Unit	Hot Water Million Btu Per Unit	Steam (Million Btu/Unit) To 300°F	300-500°F	Over 500°F	Direct Fuel Million Btu Per Unit	Exhaust Stream Temperature °F	Energy Million Btu Per Unit
Ethylbenzene	0.013	-	5.78	-	-	-	-	-
Styrene	0.246	-	23.51	-	-	2.00***	500	0.72
Total	0.259	-	29.28	-	-	2.00***	500	0.72

* Unit output denotes one ton in the case of styrene and 1.15 tons in the case of ethylbenzene (as 1.15 tons of ethylbenzene are required to produce one ton of styrene).

** Assuming 3413 Btu/Kwh

*** An additional 2.9 million Btu/ton of fuel (internally generated gas) is consumed as fuel. The 2.0 million Btu/ton figure refers to purchased natural gas.

EXHIBIT 2865-6

HISTORIC AND PROJECTED U.S. PRODUCTION OF STYRENE

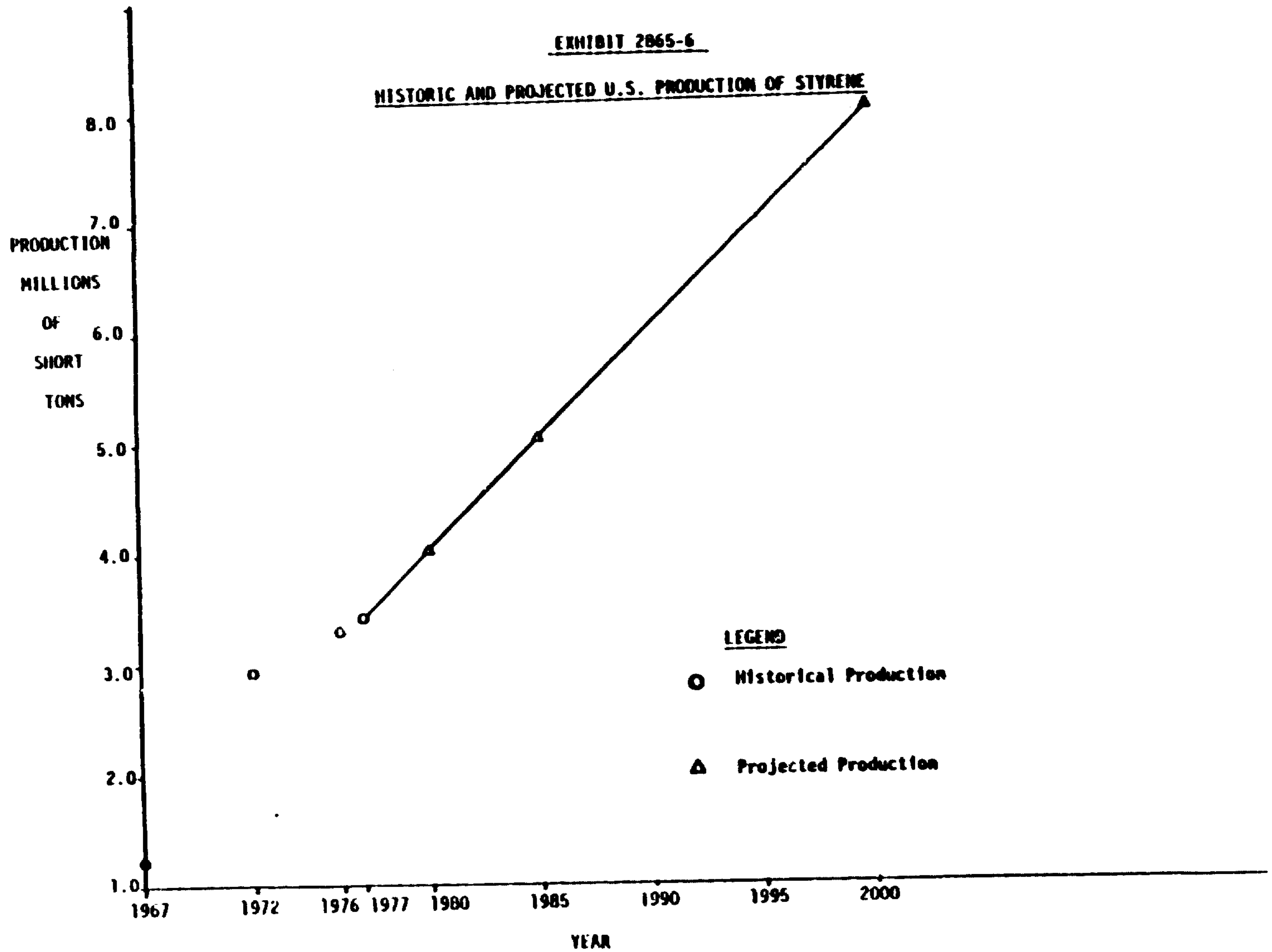


EXHIBIT 2865-7

ESTIMATED ANNUAL ENERGY CONSUMPTION IN STYRENE PRODUCTION FOR SELECTED YEARS

(10^{12} Btu)

	1975[1] (Base Year)	1985[3]	2000[4]
Purchased Fuel	90.35	162.80	232.64
Purchased Electricity[2]	0.61	1.21	2.31

1. From Exhibit 2865-3
2. Electricity converted to Btu's at 3413 Btu/kWh
3. Data for 1985 based on the following assumptions:
   a) 50% of new capacity via the hydroperoxide process.
   b) conventional process 18% less energy consumption than levels reported in Exhibit
   c) total styrene production in 1985 is 5.19 million tons, as per Exhibit 2865-6.
   d) boilers assumed 80% efficient.
4. Data for 2000 based on the following assumptions:
   a) 50% of post 1985 capacity via the hydroperoxide process.
   15% of post 1985 capacity via stilbene process.
   35% of post 1985 capacity via the conventional process.
   b) total styrene production in 2000 is 8.08 million tons, as per Exhibit 2865-6.
   c) boilers assumed 80% efficient.
   d) all ethylbenzene production at 1985 efficiency.

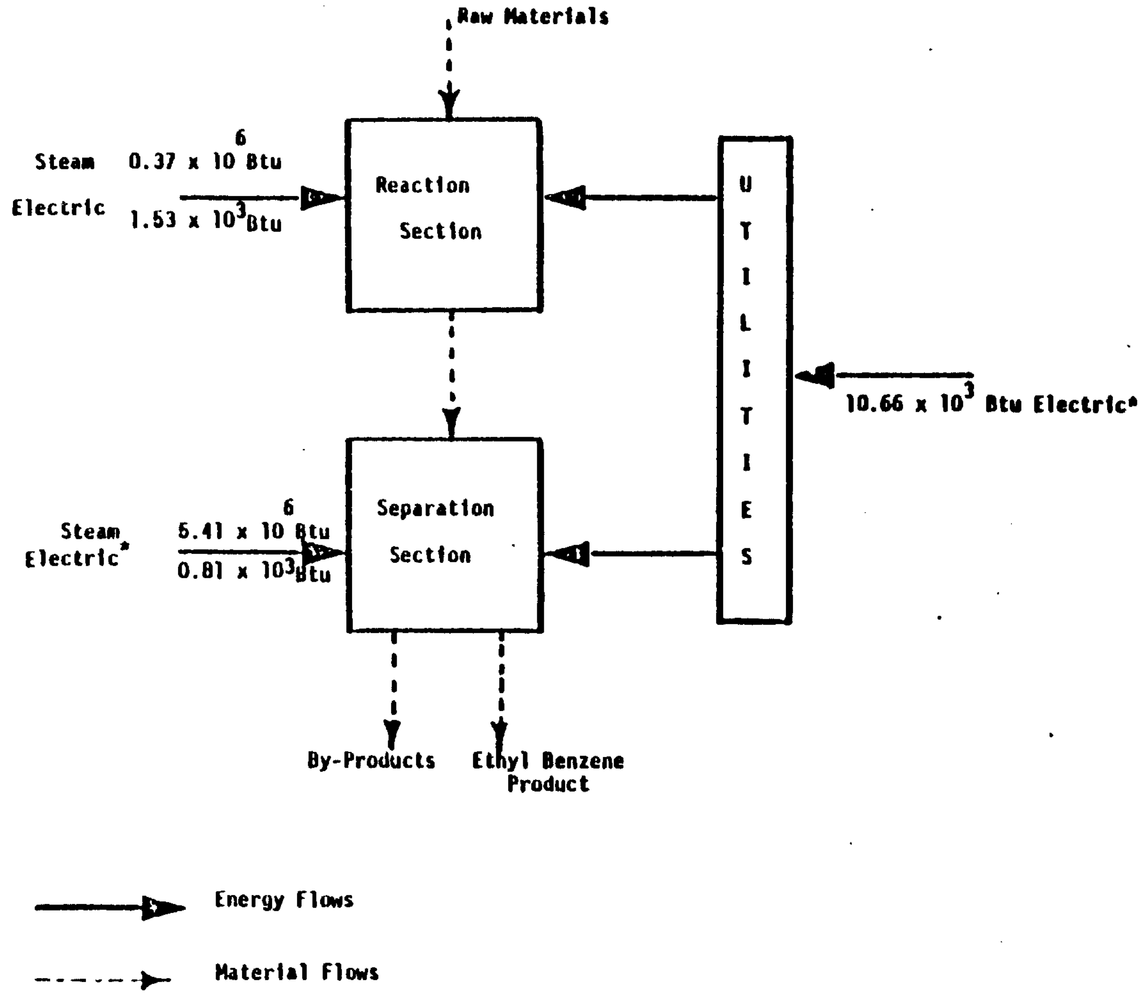
EXHIBIT 2865-8

STYRENE/ETHYLBENZENE PLANT FACTORS

TYPICAL PLANT CAPACITY TONS/YEAR	PLANT SIZE RANGE TONS/YEAR	ELECTRIC LOAD FACTOR	THERMAL ELECTRIC COINCIDENCE FACTOR	PROJECTED APPLICABILITY TO 2000
500,000	40,000-750,000	0.9	1.0	Good

EXHIBIT 2865-9

ETHYLBENZENE ENERGY FLOW SCHEMATIC
(BASIS: 1.15 TONS OF PRODUCT)



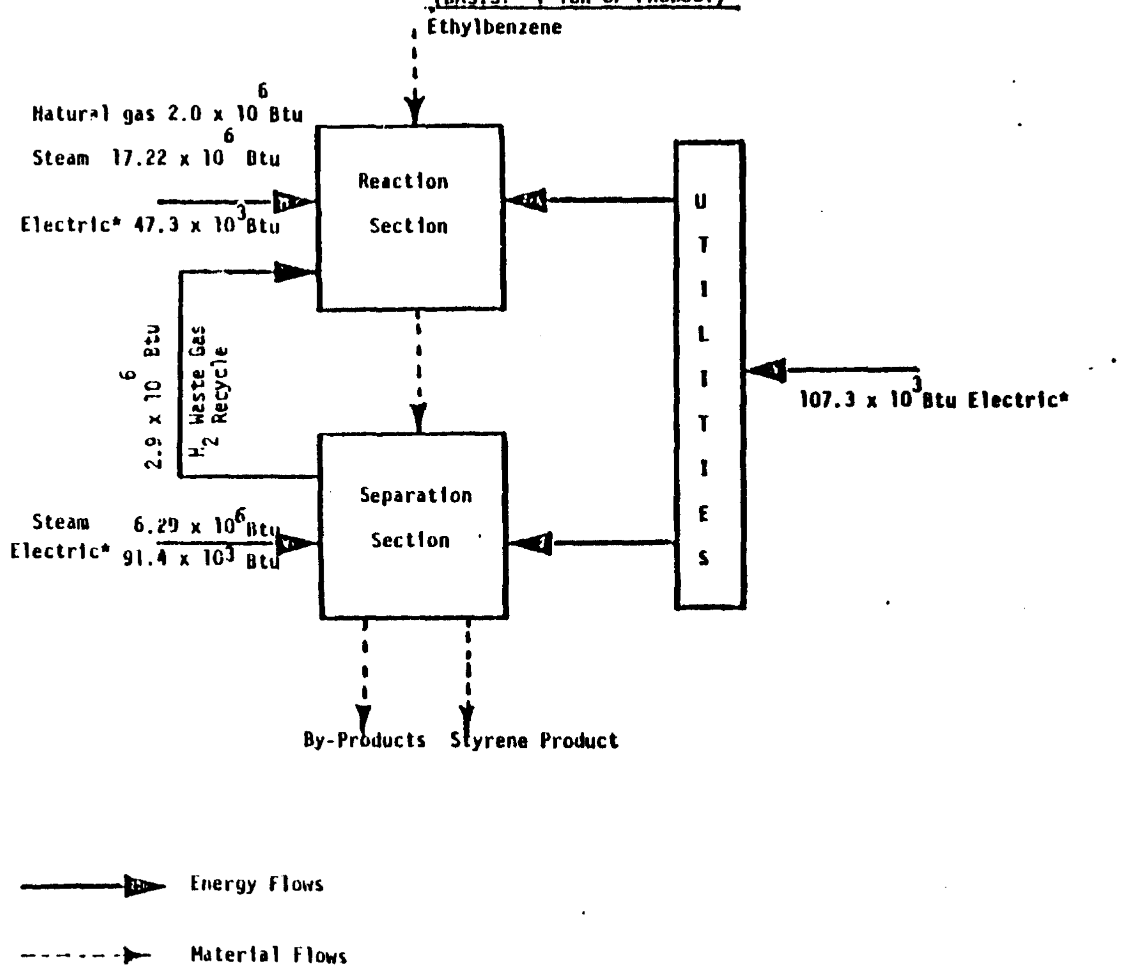
Note: Utilities include energy for pumping cooling water, etc.

* Electric energy at 3413 Btu/kWh

EXHIBIT 2865-10

STYRENE ENERGY FLOW SCHEMATIC

(BASIS: 1 TON OF PRODUCT)



Note: Utilities include energy for pumping cooling water, etc.

*Electric energy at 3413 Btu/kWh

ETHYLENE PRODUCTION

1.0 PROCESS IDENTIFICATION

This section identifies and specifically defines the industry, and provides a brief description of the current manufacturing process employed.

1.1 SIC Classification

The production of ethylene is included in the Standard Industrial Classification code 2869, which covers "industrial organic chemicals not elsewhere classified." This category includes, in addition to ethylene, some of the largest selling chemicals by volume in the U.S. SIC 2869 is part of the two digit classification 28, "Chemical and Allied Products".

1.2 Process Description

Ethylene is produced by the high temperature pyrolysis (or "cracking") of hydrocarbon feedstocks which range commercially from ethane to gas oils.

Exhibit 2869-1 is a simplified diagram of a plant for the production of ethylene and other co-products by the pyrolysis of a liquid hydrocarbon feedstock.* The feedstock is preheated, mixed wi' : steam and then passed through the tubes of the pyrolysis furnace in which the temperature is raised to around 1600°F. Residence time in the furnace is short, being typically less than 0.5 seconds in a modern plant. The net result of this

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* The same processing sequence is used, with minor modifications, for all feedstocks, but gas cracking calls for a simpler and less expensive plant.

process is the production of a furnace effluent that is largely olefinic compared to the mainly paraffinic feed and with a considerably lower average molecular weight. Much of the development effort in recent years has been aimed at optimizing furnace conditions to maximize the yield of ethylene in the furnace effluent.

The furnace effluent is quenched rapidly to below 800°F on exit from the furnace in order to minimize undesirable side reactions. This operation is normally carried out in quench boilers which generate high pressure steam for use within the plant. Additional quenching may be carried out by the injection of a suitable quench oil. The quenched furnace effluent is fed to the primary fractionator tower which splits it into three crude components. The lightest of these is a gas fraction consisting primarily of hydrogen and the C_1 to C_4 hydrocarbons, including ethylene. The other two fractions are pyrolysis gasoline and fuel oil. After stripping to remove light ends, these two streams can be withdrawn as liquids and then routed to storage.

The remainder of the process is devoted to the purification and separation of the gas fraction from the primary fractionator. The gas stream is compressed in a multistage compressor to around 500 psig. Hydrogen sulphide and carbon dioxide impurities are removed by scrubbing with caustic soda solution and water. In view of the low boiling points of the components to be separated, several of the fractionation towers are operated at high pressure and low temperature (as low as 200°F). A large refrigeration plant is required, therefore, to chill the feed to the fractionation section and to provide low temperature coolant in the

condensers of several distillation towers. The fractionation sequence shown in Exhibit 2869-1 is typical of those used in the industry but a number of variations can be adopted. The hydrogen and methane byproducts which are separated first are used primarily as fuel although some hydrogen is generally used for pyrolysis gasoline hydrogenation and in the acetylene converters. The purpose of the acetylene converters is to remove the reactive acetylenic byproducts of the cracking process that would otherwise remain as unacceptable impurities in the ethylene and propylene products. The ethylene and propylene products are usually stored at atmospheric pressure and low temperature in refrigerated tankage.

Ethane byproduct is recycled to the pyrolysis section and cracked separately in order to increase further the ethylene yield. Ethane is a particularly favorable feedstock when maximum ethylene yield is required.

A feature of modern ethylene technology is the high degree of heat recovery and the integration of the fuel, steam and power utility systems. Current practice uses fired fuel (usually byproduct hydrogen/methane) as the primary source of energy. Heat recovery from the furnace effluent provides high pressure steam which may satisfy around two-thirds of total plant steam requirements. The deficit is supplied by generating additional steam in auxiliary boilers.

Ethane and propane, recovered from natural gas, are the dominant feedstocks for ethylene production in the U.S. (Exhibit 2869-2).

New capacity and plant under construction are increasingly designed with flexibility to process liquid feedstocks as a result of limited natural gas availability. European and Japanese steam crackers are based mainly on liquid feedstocks.

Exhibit 2869-3 shows typical yields with various feedstocks. As can be seen the yield of ethylene decreases as the feedstock becomes heavier. Ethane crackers produce such a high yield of ethylene that by-product recovery is generally not economic. When propane is cracked, propylene is usually recovered in addition to ethylene. Liquid feed crackers usually recover the full range of byproducts, including butadiene and BTX in order to achieve optimum economics. Byproducts recovery is important with liquid feed crackers since they are larger and more expensive to build than gas feed crackers producing equivalent amounts of ethylene.

When cracking liquid feeds the effect of operating conditions on the yield structure can be significant and the production ratio of ethylene to propylene can be adjusted within a considerable range. The yields shown in Exhibit 2869-3 should therefore be considered as typical which can be governed by operating conditions as well as the exact nature of the qualities of the different feedstocks within each feedstock category.

The plant sizes are typical of the majority of large plants purchased in the reference time period. Economies of scale are currently significant up to about 450,000 metric tons per year. Above this capacity, economies of scale are small and become minimal at the level of 600,000 metric tons per year. Technological improvements will no doubt make possible in the near future the construction of larger single train plants to which significant economies of scale apply. It should be recognized however, that although on paper, considerable economies of scale may be predicted with increasing plant size, there are practical constraints, such as plant reliability, higher lost income during planned or unexpected shutdowns, and possible construction delays, that would tend to inhibit the rapid growth in single train plants that was experienced in the past. We expect that by the end of the century new large plants coming on stream will be in the range of 0.8 - 1.0 million metric tons of annual production capacity for ethylene.

2.2 Annual Energy Consumption

The U.S. Census Bureau reports the following consumption of energy by SIC code 2869[1].

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(1) U.S. Dept. of Commerce, "Annual Survey of Manufactures", Fuels and Electric Energy Consumed, 1978 Edition.

1975 ENERGY CONSUMPTION, SIC 2869

ENERGY SOURCE	CONSUMPTION
Fuel Oil: Distillate	14.95×10^{12} BTU
Residual	30.69×10^{12} BTU
Coal	81.82×10^{12} BTU
Natural Gas	712.84×10^{12} BTU
Other Fuels (1)	50.81×10^{12} BTU
Purchased Electricity	$18{,}608.7 \times 10^{6}$ kWh
Total Fuel & Electricity (2)	954.62×10^{12} BTU
Self-generated Electricity (3)	$7{,}170.9 \times 10^{6}$ kWh

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(1) Including fuels not specified by kind.

(2) Electricity equivalence at 3413 BTU/kWh.

(3) Fuels used to generate electricity on-site are already included in the individual fuel consumptions above.

As mentioned in Section 1.1, ethylene is not the only product included in SIC 2869. Data from the U.S. Census Bureau are therefore not available for the production of ethylene as indeed for any chemical included in this category. The FEA (Target) document [1] for SIC 2869 estimates the following production and energy consumption data for 1972:

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(1) Battelle Columbus Laboratories, "Developing a Maximum Energy Efficiency Improvement Target for SIC 28", Federal Energy Administration, July 1, 1976.

Chemical	BTU/lb	Production Billion lbs	Total Process Conversion Energy, Billions BTU
Ethylene:Ethane,etc. Cracking	11700	8.34	97590
Ethylene:Naphtha Cracking	6060	4.17	25270
			122860
Total SIC 2869		125.40	671000
% Ethylene		10.0	18.3

It appears however that not all ethylene produced in 1972 has been included in the reported production which, according to Exhibit 2869-7, is close to 9.5 million metric tons or 20.85 million pounds. Also, the total process energy used in SIC 2869 during 1972 of 671×10^{12} BTU has apparently been revised to 1122×10^{12} BTU, according to the Federal Register, Vol. 42, No. 111, June 9, 1977.

The following table reconstructs the 1972 data using the numbers discussed above for ethylene production and total energy use, but maintains the numbers that appeared in the "target" documents for BTU/lb and total SIC 2869 production. It is assumed that ethylene in excess of that reported in the "target" document has been produced by gas cracking.

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(1) Electricity equivalence at 3413 BTU/KwH

Chemical	BTU/lb	Production Billion lbs	Total Process Conversion Energy, Billions BTU
Ethylene:Gas Cracking	11700	16.68	195,156
Ethylane:Naphtha Cracking	6060	4.17	25,270
			220,426
Total SIC 2869		125.40	1,122,000
% Ethylene		16.6	19.6

It therefore appears that of the total energy consumed in SIC 2869, about 20% is for the production of ethylene. The energy consumption of 6060 BTU/lb of ethylene produced in naphtha cracking is the result of apportionment of the energy among products as shown in Exhibit 2869-10. If no apportionment is used, the percent of energy consumed in SIC 2869 for the production of ethylene is about 22%. Applying these percentages to the 1975 energy consumption of 954.6×10^{12} BTU in SIC 2869, the estimated consumption for ethylene production, as shown in Exhibit 2869-11, is 189×10^{12} BTU with energy apportionment and 210×10^{12} BTU without apportionment. If the detailed data presented in Section 3 for unit energy consumption are applied to the actual 1975 ethylene production, energy requirements are calculated as 250×10^{12} BTU. It is believed that this latter figure is a closer estimate, since the percentages developed from the "Target" document ignored ethylene production from gas oil which requires more energy. Note that no apportionment of energy to by-products has been taken in the derivation of this estimate.

It should be pointed out that all fuel needs for ethylene production are usually met by firing fuels produced in the cracking process. The large majority of the pyrolysis furnaces installed up to now are fired

with gas. The fuel gas burned in the furnaces consists mainly of the methane fraction from the ethylene plant. Gas oil cracking however does not produce methane in sufficient quantity for firing the pyrolysis furnaces. Dependent on gas oil quality and cracking severity, the methane fraction in a gas oil cracking plant covers about 50-80% of the required firing duty[(1)]. The remaining needs can be provided either by imported fuel gas or by fuel oil. Since fuel oil yields are high in gas oil cracking it appears advantageous to use this oil for firing in the furnaces.

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(1) Dr. B. Lohr and H. Dittman, "Design Matches Furnaces to Needs", OGJ, Oct. 17, 1977, P. 65.

2.0 NATIONAL DATA

2.1 Capacity and Production Data

Total installed nameplate capacity in the U.S. was just under 13 million metric tons in mid-1977 compared to a free world total of about 35 million. A breakdown of the U.S. capacity by company and by location is given in Exhibit 2869-4. Exhibit 2869-5 shows world capacity by geographical areas. It is estimated that the U.S. capacity will increase to nearly 18 million metric tons by 1980. Year end capacity and annual additions by company based on current construction plans are shown in Exhibit 2869-6.

Ethylene is the most important building block of the petrochemical industry. Its growth rate in the U.S. averaged 11.3% per year from 1961 to 1974. Production declined in 1975, relative to 1974, but showed some improvement in 1976 and in 1977; ethylene production for the years 1961 to 1977 is shown in Exhibit 2869-7. The percentage end uses of ethylene production are shown in Exhibit 2869-8 for the years 1974 to 1976.

Steam crackers currently in operation range in size from 50,000 to over 500,000 metric tons of annual ethylene production capacity. The smaller plants are obviously old and uneconomic to operate, compared with their modern large counterparts, and would be prime candidates for closure in the event of overcapacity.

The drive towards larger plants was the result of improved technology, increasing demand and economies of scale. In the 1950's, the capacities of new plant coming onstream were about 125,000 metric tons per year. Typical economic plant sizes at various time periods are shown in Exhibit 2869-9.

3.0 PROCESS ENERGY REQUIREMENTS

This section describes in depth the energy consumed per unit of production in ethylene manufacture, as well as providing details on the type of energy required.

3.1 Unit Energy Consumption Data

The cracking of gaseous and liquid hydrocarbons for the production of light olefins requires large amounts of energy. Most of the energy, in the form of fuel, is consumed to supply process heat for the pyrolysis section.

Typical energy requirements for modern plants producing 450,000 metric tons of ethylene per year are shown in Exhibit 2869-12. It will be noted that unit energy requirements increase as the feedstock becomes heavier.

3.2 Details of Electricity Consumption

Ethylene plants operate continuously and use electricity primarily for rotating equipment such as pumps, air cooler motors and small blowers. Electricity consumption is therefore essentially constant and the only major interruptions occur during plant shutdowns.

3.3 Details of Thermal Energy Consumption

Large quantities of fuel are consumed in the pyrolysis section. This, combined with the very high temperatures involved, make extensive heat recovery attractive in modern steam crackers. It is now normal practice

to generate high pressure steam ($\sim$ 600 psig in a gas cracker, or $\sim$ 1500 psig in a liquid cracker) in waste heat boilers and to use this steam to drive the major process compressors. Medium pressure steam from the compressor turbine exhausts is available to supply process heat, such as reboilers, and as reaction diluent in the furnaces. There is usually a deficit of high pressure steam, necessitating an import to the process from external boilers and a surplus of medium pressure steam for export.

Steam consumption can vary considerably depending on plant complexity and design philosophy. Some modern plants are almost self sufficient when operating at design capacity. However, this self sufficiency is the result of large internal production and equally high consumption. When a plant is operated at reduced capacity serious imbalances occur since steam production is linked to the plant's operating capacity whereas consumption is not. Steam requirements shown in Exhibit 2869-12 are typical for a 450,000 metric ton per year plant cracking naphtha.

4.0 ANTICIPATED TRENDS

This section discusses the trends which are likely to occur in the industry through the year 2000. The major emphasis is on the areas of product growth, process technology, and energy consumption.

4.1 Product Growth Trends

Ethylene is ranked as the number one volume organic chemical produced in the world. It is used as a raw material for a large number of products such as plastics, fibers and antifreeze compounds. Up to 1974 its growth rate had been spectacular, but in 1975, for the first time in the product's history, a severe decline was experienced in consumption. This decline was however, in line with the economic climate prevailing during that year, and in 1977 the consumption was higher than that in 1974.

It has been estimated[(1)] that ethylene consumption will grow by about 6.5% per year to 1985. This appears to be a reasonable projection representing neither an optimistic nor a pessimistic opinion. This estimate has been prepared by projecting growth rates for the major ethylene derivatives as shown in Exhibit 2869-13. The gradual decline in the growth rate of ethylene is attributed to the fact that many of the major ethylene derivative markets are either in, or approaching the final stages of their market life growth curve.

Despite the relative decline in the growth rate, ethylene will remain the most important petrochemical building block and one of the

(1) Dr. R.G. Minet and F.W. Tsai, "Feedstock Outlook Changing in U.S.", O & G Journal, Mar. 21. 1977, p. 135.

fastest growing major chemicals. With the development and growth of new applications, demand for ethylene is expected to average 5.5% per year from 1985 to 2000. Ethylene production since 1961 and future projections are shown in Exhibit 2869-14.

4.2. Process Changes

Process changes and developments over the past few years have centered in using heavier raw materials, optimizing ethylene yields, and achieving maximum heat integration. The U.S. ethylene industry has traditionally been based on natural gas liquids, with ethane, or mixtures of ethane and propane, as the main feedstocks. Until the beginning of this decade these liquids were plentiful and cheap and, since they also give high ethylene yields, were the most desirable feedstocks. During the early 1970's shortages were experienced in natural gas and associated liquids. The shortages were and are expected to continue and the availability of natural gas liquids to decrease further. This prompted ethylene manufacturers to start considering the use of liquid feedstocks for new capacity. This trends was given an added boost when OPEC raised oil prices in late 1973 to early 1974 which resulted in a rapid increase in the prices of ethane and propane.

When using liquid raw materials, the yield of ethylene per ton of feed is less than when using ethane and propane. This has two important implications. The first is that a liquid cracker is considerably larger and more complex (thus more expensive) than a gas cracker of identical ethylene output. The other is that since the ethylene yield is low, the recovery of byproducts is essential to ensure the economic viability of the plant.

The use of liquid feedstocks together with the large volume of byproducts that can be recovered would indicate that a new liquid cracker would best fit in an integrated petrochemical complex that could provide the raw material and use the ethylene and the co-byproducts on-site. Such an arrangement would also provide the opportunity for efficient heat integration.

An estimate of the feedstock requirement up to year 1985 and 2000 is shown in Exhibit 289-15. Although natural gas production is expected to decrease, ethane supply from natural gas will increase due to improved cryogenic extraction techniques, at least until 1985. It is thereafter assumed to remain constant till the end of the century. Because of alternate uses of LPG for household and commercial heating, it is expected that propane will be used less as a petrochemical feedstock. Butane on the other hand is expected to be used more, although it will remain a small portion of total feedstock supply.

Naphtha and gas oil will make the bulk of the feedstocks in the year 1985 and increasingly so in the year 2000. Naphtha will prbably be preferred as a feedstock because of byproduct disposal problems that will be encountered with gas oil cracking. However, naphtha availability may constrain its use, although it will be probably easier to resolve this problem by importing naphtha than to cope with the byproduct disposal. It will therefore, be assumed that the naphtha to gas oil ratio remains at the mid 1980's level until 2000. Based on the feedstocks shown in Exhibit 2869-15, the production of ethylene and co-products will be as shown

in Exhibit 2869-16. It is anticipated that crude oil will be used as a feedstock in the near future. If this occurs it will release some naphtha and gas oil. It is not expected however that crude oil will be used in large quantities in the timeframe under review.

4.3 Implementation of New Technology

Anticipating possible difficulties in obtaining adequate supplies of the feedstocks currently in use has prompted some companies to examine alternate feedstocks. One Australian company has developed a process for the production of ethylene, propylene, aromatics, and tar products by cracking hydrocarbon residual streams[1]. It appears however that this process has not been adopted by any other ethylene producer.

The use of crude oil as a possible feedstock has attracted considerable attention. The advantage that crude oil would have over other alternate feedstocks is that it would eliminate the need for an atmospheric distillation unit. This should be attractive to purely chemical companies not engaged in the oil business. Union Carbide and Dow Chemical have developed crude oil based processes to the pilot plant stage. These processes are projected to be commercial by the mid to late 1980's and, as they claim cost advantages over conventional crackers, they may eventually become an important new route to ethylene production.

The use of synthesis gas as a petrochemical feedstock has been considered for many years, but no successful process has yet been reported.

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(1) "Crude residual feeds petrochemical process", Oil and Gas Journal, November 26, 1973, p. 73.

Undoubtedly there will be considerable effort in the future to develop an economic synthesis gas process for the production of ethylene. Such a process could use as a feedstock any carbon source that could be readily gasified and would thus free the petrochemical industry from its reliance on crude oil and natural gas for its viability. Developments in this field are not expected to result in significant quantities of ethylene production during this century.

4.4 Trends in Energy Requirements

The FEA "Target" document estimates that by applying a number of energy saving techniques to a new cracker, a 19% reduction in fuel requirements could be achieved compared to a plant of pre-1973 design. The FEA "Target" for SIC 2689 is a 17.0% reduction in unit energy consumption by 1980 relative to 1972. Neither of the above two estimates is directly applicable to this study. Using the former would tend to ignore existing capacity which cannot achieve the 19% objective by 1985. The latter applies to the whole SIC 2689 code of which ethylene is only a small part.

A 19% improvement on the unit consumption numbers shown in Section 3 can, however, be considered as reasonable for the year 2000 considering continuing advances in technology and when most of the existing capacity will have been replaced. For 1985 a 9% improvement is a realistic target.

Exhibit 2869-17 present estimates for the industry's energy consumption in 1985 and 2000 based on the assumptions stated above.

5.0 PLANT-SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements including indications of load profiles, state conditions and reliability considerations. Several plant factors are summarized in Exhibit 2869-18.

5.1 Load Profiles

Ethylene is produced in a continuous process. Electric energy consumption at capacity is therefore essentially constant over the entire year and the electric load factor is close to one. The power load is estimated to be approximately 50% fixed and 50% variable with capacity. For practical purposes, the mimimum throughput operation of a plant can be considered to be around 50% of full capacity. The minimum electric load will therefore be about 0.75 when the plant operates at minimum throughput. Due to the continuous nature of the entire operation, the need for steam coincides with the electrical requirements. Hence Exhibit 2869-18 illustrates a thermal-electrical coincidence factor of 1.0.

5.2 Energy Flow Schematics

As indicated in Section 3.3. most of the energy is consumed in the pyrolysis section. Some of this energy is recovered through steam generation. In a typical new generation naphtha cracker producing 450,000 metric tons of ethylene per year, steam requirements are about

233 tons per hour of 1500 psig steam at 850°F (i.e. 4.5 tons of steam per ton of ethylene). Of this, 183 tons are generated by utilizing heat from the pyrolysis section and 50 tons/hour are generated in an auxiliary boiler. This steam is used to drive the process gas compressors and the propylene refrigeration compressors whose horsepower is 26,500 and 22,300 respectively. The exhaust steam is used in the ethylene refrigeration compressor of 9,200 horsepower and major process pumps, also of 9,200 horsepower.

5.3 State Conditions and Mass Flows

As illustrated in Exhibit 2869-12 the imported steam is normally over 500°F. The same applies to the internally generated steam which together with the imported, is used to drive the major process compressors. The steam from the compressor turbine exhausts is used to supply process heat to drive some pumps, and as reaction diluent in the furnaces.

Mass flows are as shown in Exhibit 2869-3. It should be recognized however, that these balances are gross and that in all probability gas and/or fuel oil will be used for internal energy requirements.

5.4 Reliability Considerations

Ethylene manufacture is a continuous, steady-state process in which flow rates, temperatures, pressures and levels are generally in balance at any time. A high degree of routine or continuous monitoring of conditions, using sophisticated instruments, is employed to assist in maintaining the balance. The loss of any utility supply immediately

upsets the process balance. Loss of water to coolers and condensers results in pressure rise and venting of hydrocarbons to atmosphere or a safety system. Loss of electric power can upset the instrument controls and stop a large number of pumps with various undesirable consequences. If any of the consequences cause loss of flow through furnace tubes, tube failures can result. Although a multitude of safety devices are incorporated into the design to ensure safe venting and orderly shutdowns, a risk of fire and/or explosion is always present. For these reasons, manufacturers take every action possible to ensure that utility supplies are dependable, and particular emphasis is paid to electric power.

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SIMPLIFIED ETHYLENE UNIT

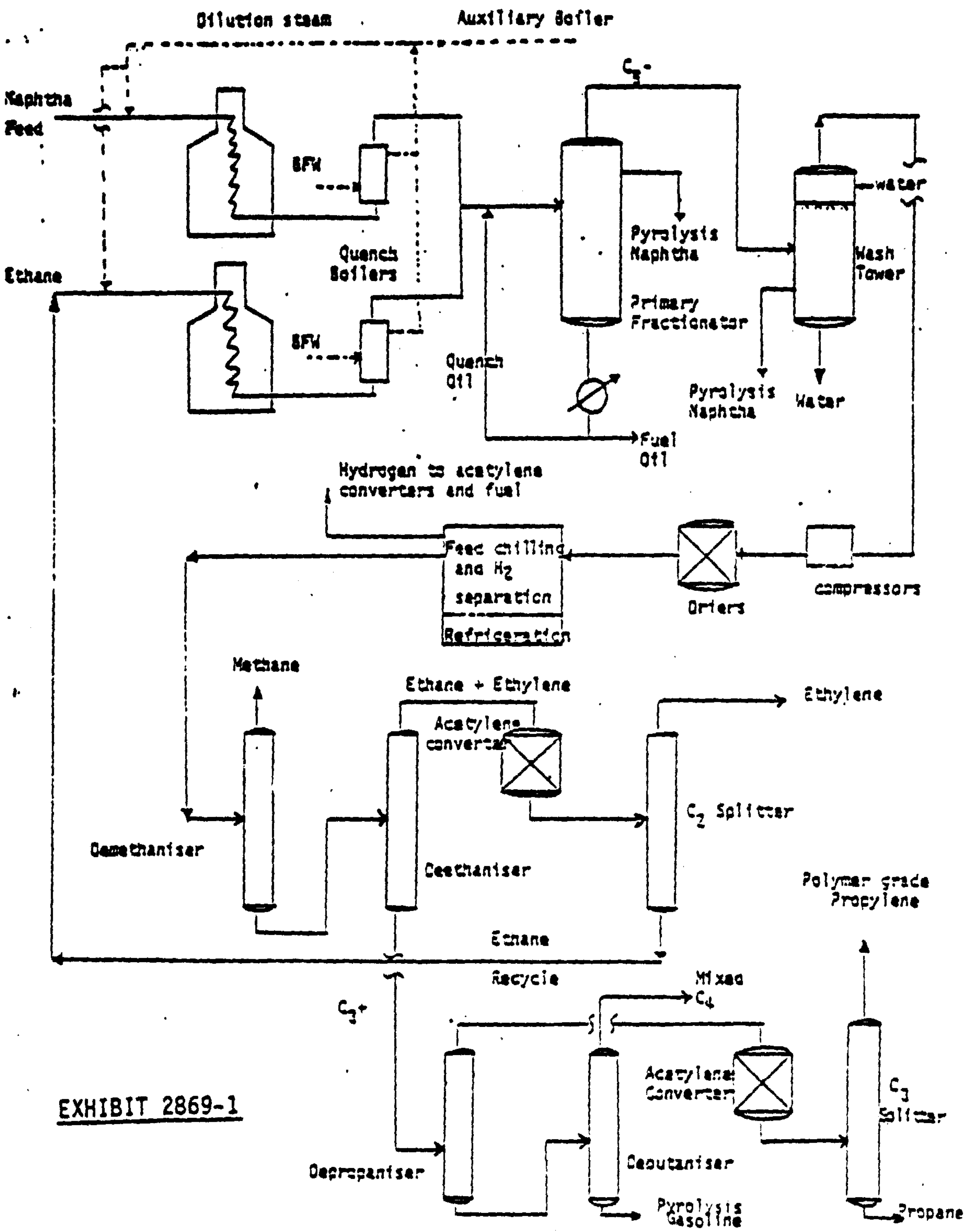

EXHIBIT 2869-1

EXHIBIT 2869-2

ETHYLENE FEEDSTOCKS

	MILLION BARRELS/YEAR		
	1974	1975	1976
Ethane	111	107	117
Propane	81	49	46
Butane	11	4	15
Natural Gasoline	6	8	8
Naphtha	22	18	24
Raffinate	1	1	2
Gas Oil	36	33	34

Source: Dr. R.G. Minet, F.W. Tsai, "Feedstock Outlook Changing in U.S.", Oil and Gas Journal, Mar. 21, 1977, p. 135.

EXHIBIT 2869-3

ETHYLENE AND COPRODUCTS YIELDS FOR VARIOUS FEEDSTOCKS

	WEIGHT %					
	Ethane	Propane	Butane	Naphtha	Atmospheric Gas Oil	Vacuum Gas Oil
Offgas	11.8	27.2	22.2	14.4	11.6	9.4
Ethylene	80.0	42.5	39.0	29.0	25.1	21.2
Propylene	2.5	20.5	16.8	15.7	14.8	14.6
Total C4	3.2	4.2	8.3	10.5	9.6	11.3
Pyrolysis Gasoline	2.3	4.6	11.2	18.7	18.0	15.3
Fuel Oil	0.2	1.0	2.5	11.7	20.9	28.2
	100.0	100.0	100.0	100.0	100.0	100.0

Source: Dr. R.G. Minet and F.W. Tsai, "Feedstock Outlook Changing in the U.S.", Oil & Gas Journal , Mar. 21, 1977.

EXHIBIT 2869-4

INSTALLED ETHYLENE CAPACITY - JUNE 30, 1977

Company	Location	Capacity, metric tons/year
UNITED STATES		
Allied Chemical Corp. (with Borg-Warner Chemicals and BASF-Wyandotte)	Geismar, La.	328,000
ARCO Chemical Co.	Watson, Calif.	33,000
	Lyondell, Tex.	590,000
ARCO Polymers	Houston	227,000
Amoco Chemicals Corp.	Chocolate Bayou, Tex.	455,000
Chemplex Co.	Clinton, Iowa	226,860
Cities Service Co.	Lake Charles, La.	400,000
Conoco Chemicals	Lake Charles, La.	295,000
Dow Chemical Co.	Bay City, Mich.	90,000
	Freeport, Tex.	1,136,000
	Plaquemine, La.	545,000
Du Pont	Orange, Tex.	375,000
Eastman Chemical Products	Longview, Tex.	580,000
El Paso Products Co.	Odessa, Tex.	234,500
Exxon Chemical U.S.A.	Baton Rouge, La.	900,000
	Baytown, Tex.	36,000
	Bayway, N.J.	90,000
B. F. Goodrich	Culvert City, Ky.	136,000
Gulf Oil Chemicals Co.	Port Arthur, Tex.	544,000
	Cedar Bayou, Tex	726,000
Jefferson Chemical Co.	Port Neches, Tex.	240,000
Mobil Chemical Co.	Beaumont, Tex.	410,000
Monsanto	Texas City, Tex.	45,000
	Alvin, Tex.	295,000
Northern Petrochemical	Morris, Ill.	400,000
Olin Corp.	Brandenberg, Ky.	90,000
Phillips Petroleum	Sweeney, Tex.	515,000
Shell Oil Co.	Norco, La.	665,000
	Houston	715,000
Sun-Olin	Claymont, Del.	109,000
Union Carbide	Seadrift, Tex.	454,500
	Taft, La.	227,000
	Texas City, Tex.	454,500
U.S.I.	Tuscola, Ill.	410,000
	U.S. total	12,977,360

Source: Ted West, "Ethylene Capacity is Plentiful", Oil & Gas Journal, Oct. 17, 1977, Page 51.

EXHIBIT 2869-5

INSTALLED WORLD CAPACITY BY AREAS- JUNE 30, 1977

	Metric tons/year
NORTH AMERICA	
U.S.	12,977,360
Canada	725,000
	13,702,360
LATIN AMERICA	
Argentina	55,000
Brazil	690,300
Chile	60,000
Colombia	16,000
Mexico	14,000
Puerto Rico	904,500
Venezuela	150,000
	1,839,900
ASIA/PACIFIC	
Australia	[illegible]
China (Taiwan)	514,500
India	60,000
Japan	4,912,500
Korea	100,000
	5,716,000
WESTERN EUROPE	
Austria	105,000
Belgium	500,000
Denmark	43,000
Finland	165,000
France	2,220,000
West Germany	3,955,000
Italy	1,820,000
Netherlands	2,355,000
Spain	351,000
Sweden	350,000
U.K.	1,650,000
	13,514,000
OTHERS	
Greece	15,000
Israel	24,000
South Africa	150,000
Turkey	55,000
	244,000
World Total	35,066,160

Source: Ted West, "Ethylene Capacity is Plentiful", Oil and Gas Journal, Oct. 17, 1977, Page 54.

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EXHIBIT 2869-6

U.S. YEAR END ETHYLENE CAPACITY
(Million Metric Tons)

	1977	1978	1979	1980
Prior Year's Capacity	12,020	13,608	15,106	17,102
Additions by Company				
AMOCO		454		
ARCO	590		590	
DOW			544	
EXXON			295	295
EL PASO	91			
GULF	544			
PHILLIPS		227	227	
SHELL	363		340	340
TEXACO		454		
UNION CARBIDE		363		
Total	1588	1498	1996	635
Year End Capacity	13608	15106	17102	17737

Source: Arnold J. Cahill, "Ethylene - Past, Present, Near-Term Future", CEP, July, 1977.

EXHIBIT 2869-7

U.S. ETHYLENE PRODUCTION

YEAR	THOUSAND METRIC TONS
1961	2656
1962	2850
1963	3410
1964	4341
1965	3920
1966	5099
1967	5376
1968	5965
1969	7455
1970	8392
1971	8369
1972	9458
1973	10128
1974	10670
1975	9298
1976	10195
1977	11204

Source: 1961 to 1974: Trends in Petrochemical Technology, Arthur M. Brownstein, Petroleum Publishing Company.

1975 to 1977: C & EN, Dec. 19, 1977

EXHIBIT 2869-8

ETHYLENE END USE

	WEIGHT %		
	1974	1975	1976
Low Density Polyethylene (LDPE)	26.4	26.1	26.0
High Density Polyethylene (HDPE)	13.7	13.8	14.6
Ethylene Oxide/Glycol	17.1	19.3	17.9
Vinyl Chloride	11.4	10.9	10.7
Ethyl Benzene/Styrene	9.5	8.3	8.4
Ethyl Alcohol	4.3	4.7	4.6
Aceteldehyde	3.7	4.2	3.7
Linear Alcohols	2.4	2.6	2.4
Alpha Olefins	1.7	1.8	1.6
Vinyl Acetate	1.9	2.1	1.9
Ethylchloride	1.3	1.5	1.2
Others	6.6	4.7	7.0
	100.0	100.0	100.0

Source: Dr. R.G. Minet and F.W. Tsai, "Feedstock Outlook Changing in U.S.", The Oil & Gas Journal, Mar. 21, 1977, Page 135.

EXHIBIT 2869-9

ETHYLENE PLANT DEVELOPMENT

Period	1964-67	1967-70	1970-73	Present
Nominal Plant Size -000'Metric Tons	225	340	450	540-770

Source: Edward J. Bryson and Eugene J. Dickert, "Ethylene Plant Turbomachinery", Hydrocarbon Processing, November 1977, Page 309.

EXHIBIT 2869-10

APPORTIONMENT OF ENERGY AMONG PRODUCTS FROM STEAM CRACKING OF NAPHTHA (1)

		ENERGY SHARE		
Product (2)	Amount Pounds	Fuel M Btu/lb	Electricity kwh	Total Energy Btu/lb
ethylene	1000	6035	0.0079	6060
propylene	495	2987	0.0039	3000
butadiene	136	821	0.0011	825
butylenes/butane	125	754	0.0010	757
benzene/toluene	300	1811	0.0024	1820
C_8 aromatics	52	314	0.0004	315
hydrogen	46	278	0.0004	279
Total	2154	13000	0.0171	13056

(1) Based on data provided by the Lummus Co., "Sources and Production Economics of Chemical Products, 1973-1974", McGraw-Hill, Inc., New York, 1974, p.145.

(2) In addition to these listed chemical products, the steam cracking of naphtha (and other petroleum liquids) yields pyrolysis gasoline, pyrolysis fuel oil, and a pyrolysis gas (mainly methane) with a total heating value exceeding the fuel reqirements by a singificant amount.

Source: Battelle Columbus Laboratories, "Developing A Maximum Energy Efficiency Improvement Target for SIC 28". Federal Energy Administration, July 1, 1976.

EXHIBIT 2869-11

ANNUAL NATIONAL DATA (1975) ETHYLENE PRODUCTION

Product Production Million Metric Tons	Total Energy Consumption 10^{12} BTU	Fuels 10^{12} BTU	Electricity 10^{12} BTU	Total Energy Consumption For SIC 10^{12} BTu	Percent Total Energy Consumption Represented
9.3	189(1)			954.6	20
9.3	210(2)			954.6	22
9.3	250(3)	249.5	1.0	954.6	26

(1) Calculated by applying percentage consumptions derived from "Target" with energy apportionment.

(2) As (1) but without energy apportionment.

(3) Calculated from actual ethylene production by using unit energy consumption (Section 3) to the appropriate feedstock. No energy apportionment.

EXHIBIT 2869-12

ENERGY CONSUMPTION PER UNIT OUTPUT* IN ETHYLENE MANUFACTURE

Feed Material	Electricity Million Btu ** Per Unit	Hot Water Million Btu Per Unit	Steam Million Btu per unit			Direct Fuel Million Btu Per Unit	Exhaust Streams	
			To 300°F	300-500°F	Over 500°F		Temper. °F	Energy Million Per Unit
Ethane	0.09					23.6		
Propane	0.10					27.5		
Naphtha	0.15				2.5***	32.8		
Gas Oil	0.17					35.7		

* Unit output denotes one metric ton of ethylene plus co products.

** Assuming 3413 Btu/kWh.

*** Typical net requirement in naphtha cracking for imported steam. Included in Direct Fuel. An additional 8.3 million Btu per unit is required which is generated by heat recovery in the pryolysis section.

EXHIBIT 2869-13

U.S. ETHYLENE CONSUMPTION BY END USE

	Billion lb/year					
	1974	1975	1976	1981	1985**	1986
Polyethylene-LD	6.21	5.14	5.97	8.78	11.23	11.94
Polyethylene-HD	3.22	2.71	3.36	5.51	7.62	8.27
Ethylene oxide/glycol	4.02	3.80	4.11	5.08	6.17	6.47
Vinyl chloride	2.67	2.15	2.47	3.16	4.42	4.81
Ethyl benzene/styrene	2.24	1.64	1.94	2.54	3.16	3.32
Ethyl alcohol	1.02	0.92	1.05	1.19	1.30	1.33
Acetaldehyde	0.87	0.82	0.85	0.97	1.34	1.45
Linear alcohols	0.56	0.51	0.55	0.76	0.98	1.04
Alpha olefins	0.40	0.35	0.38	0.90	1.18	1.26
Vinyl acetate	0.44	0.42	0.44	0.57	0.84	1.91
Ethylchloride	0.31	0.29	0.28	0.22	0.20	0.19
Others	1.55	0.93	1.60	1.83	1.82	1.81
Total	23.51	19.68	23.00	31.51	40.26	42.80
Million Metric Tons	10.7	8.9*	10.4*	14.3	18.3	19.4

* Do not exactly agree with numbers given in Exhibit 7 which are from a more recent publication. Differences however are not material.

** By interpolation.

Source: Dr. R.G. Minet and F.W. Tsai, "Feedstock Outlook Changing in the U.S.", Oil & Gas Journal, Mar. 21, 1977, Page 135.

ACTUAL AND PROJECTED ETHYLENE PRODUCTION

EXHIBIT 2869-14

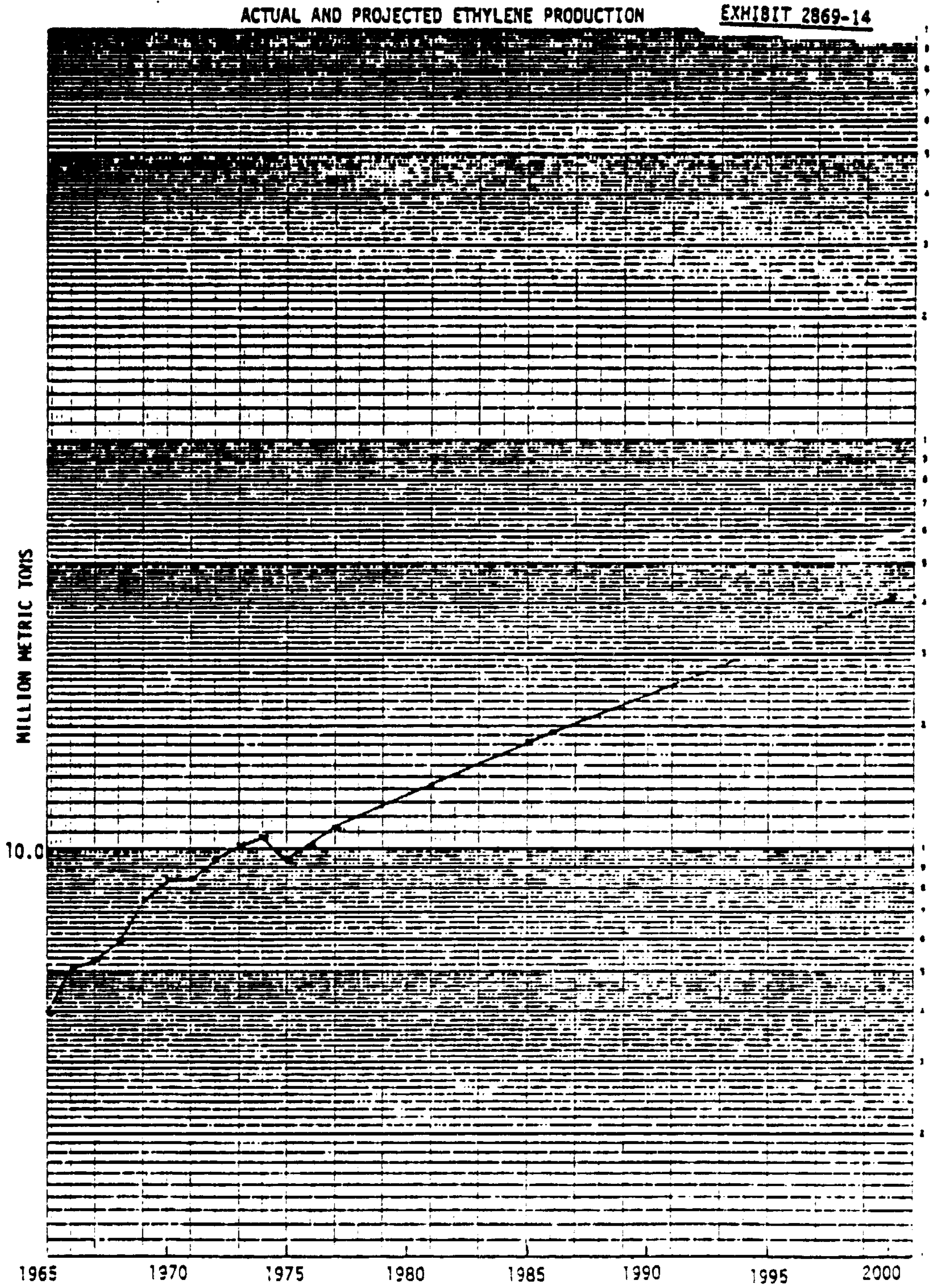

EXHIBIT 2869-15

ETHYLENE FEEDSTOCKS
(Thousand Metric Tons)

	1974	1975	1976	1981	1985 (2)	1986	2000 (2)
Ethane	6607	6369	6964	7560	7940	8036	8000
Propane	6532	3952	3710	3065	2740	2661	2000
Butane	1019	370	1389	3519	5150	5556	10,000
Naphtha (1)	3412	3176	4000	9647	19,060	21,412	68,000
Gas Oil	4800	4400	4533	9733	11,970	12,533	40,000
	22,370	18,267	20,596	33,524	46,860	50,198	128,000

(1) Includes natural gasoline and naphtha
(2) Gordian Estimate

Source: Dr. R.G. Minet and F.W. Tsai, "Feedstock Outlook Changing in U.S.", O & G Journal, Mar. 21, 1977, p. 135.

EXHIBIT 2869-16

ETHYLENE AND CO-PRODUCT PRODUCTION

	MILLION METRIC TONS			
	1981	1985	1986	2000
Ethylene	14.3	18.3	19.4	41.0
Propylene	4.4	6.3	6.8	18.8
Total C4	2.6	3.9	4.2	12.2
Pyrolysis Gasoline	4.2	6.6	7.1	21.3
Fuel Oil	3.2	4.9	5.3	16.6
Offgas	4.8	6.9	7.4	18.1
	33.5	46.9	50.2	128.0

EXHIBIT 2869-17

ESTIMATED ANNUAL ENERGY CONSUMPTION IN ETHYLENE PRODUCTION FOR SELECTED YEARS

	10^{12} BTU		
	1975(1) (Base Year)	1985(2)	2000(5)
Fuel(2)	249.5	484.6	1044.7
Electricity(3)	1.0	2.1	4.7

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(1) From Exhibit 2869-11

(2) Fuel burned is gas and fuel oil produced during cracking

(3) Electricity converted to BTU's at 3413/KwH

(4) Data for 1985 based on the following assumptions:

  (a) Unit energy consumption 9% below levels reported in Exhibit 2869-12

  (b) Total production of ethylene is 18.3 million metric tons as per Exhibit 2869-16

(5) Data for 2000 based on the following assumptions:

  (a) Unit energy consumption 19% below levels reported in Exhibit 2869-12

  (b) Total production of ethylene is 41.0 million metric tons as per Exhibit 2869-16

EXHIBIT 2869-18

ETHYLENE PLANT FACTORS

TYPICAL PLANT CAPACITY METRIC TONS/ YEAR	PLANT SIZE RANGE METRIC TONS/ YEAR	ELECTRIC LOAD FACTOR	THERMAL ELECTRICAL COINCIDENCE FACTOR	PROJECTED APPLICABILITY TO 2000 METRIC TONS/YEAR
450,000	50,000-500,000	0.90-1.0*	1.0	800,000-1,000,000

* Plant operating at full capacity

PETROLEUM REFINING

1.0 PROCESS IDENTIFICATION

This section identifies and defines the industry, and provides a brief description of the current production processes employed.

1.1 SIC Classification

The petroleum refining industry is classified under SIC code 2911. No other establishments are included under this designation.

1.2 Process Description

The earliest U.S. refineries processed crude oil principally by distillation techniques to give a distribution of products that depended mainly on the boiling range characteristics of the crude oil. During the last 30 years, two important factors have caused considerable technical changes in the industry. First, product performance and environmental requirements have demanded considerable improvements in product qualities. Second, the product distribution that can be achieved by distillation techniques fails to match market requirements. For example, U.S. gasoline demand is approximately 45% of refinery production while the yield of suitable boiling range material from the "average" crude oil would be around one half of this quantity. To meet these two requirements, the refining industry has developed processes to perform the following functions:

(1) Distillation - This is the primary operation to split the full boiling range crude oil into narrower boiling fractions suitable for downstream processing.

(2) Conversion - A series of "cracking" processes have been developed to reduce the average molecular weight of a heavy boiling feedstock. The net effect is that feedstocks such as gas oils can be cracked to yield lighter products such as gasoline and LPG.

(3) Desulfurization - sulfur compounds are removed to meet environmental requirements and also to prevent their deleterious effects on other refinery processing operations.

(4) Performance Improvement - many processes have been developed to improve important product quality criteria, such as the octane rating of gasoline or the smoke emission from aviation turbine fuels. In general, the processes involve chemical reactions to change hydrocarbon structures.

Exhibit 2911-1 is a block diagram of a U.S. refinery which includes processes to perform all of the functions outlined above.

Significant process variation exists among individual refineries, with larger refineries being, in general but not always, more complex than smaller refineries. Statistics indicating the variation in process configuration as a function of average refinery size are included as Exhibit 2911-2. Statistics indicating the variation in product distribution as a function of average refiner size are included as Exhibit 2911-3.

2.0 NATIONAL DATA

The annual national data presented in this section are summarized in Exhibit 2911-4. The derivation and significance of the production and energy consumption data are discussed in the following subsections. To conform with industry custom, production and unit energy consumption statistics are based on barrels of refinery input rather than output.

2.1 Capacity and Production Data

Total U.S. refinery runs for 1977 averaged 14.561 million barrels, per day (B/D), up from 13.416 million B/D in 1976 and 12.442 million B/D in 1975[1].

As of January 1, 1977 there were 274 operating plants (17 shut down) in fifty states. These were controlled by 148 companies with total operating capacity of 15.871 million B/D[2]. Statistics on the distribution of firm size are shown in Exhibit 2911-5 for 1970 - 1977. Statistics on the distribution of plant size are shown in Exhibit R-6 for 1977. As can be seen, there is significant variation in firm and plant size. While average plant size was 57,923 B/D, more than half of the crude processed was by refineries of over 125,000 B/D in size. At the present time, refinery technological constraints limit single refinery trains to approximately 250,000 B/D. The bulk of refinery economics of scale are achieved at somewhat lower sizes. Most refineries are comprised

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(1) Oil and Gas Journal, Jan. 30, 1978, p.134

(2) U.S Bureau of Mines, Petroleum Refineries in the United States and Puerto Rico - January 1, 1977, July 18, 1977.

of multiple trains and duplicate units. Significant variation in plant size can be expected to continue through the period 1985-2000 in view of historical government support for small refiners and product and logistic advantages for a number of small refineries. Capacity weighted plant size can be expected to continue to increase, however. A reasonable estimate of average plant size for the 1985-2000 period would be in the range of 150,000-200,000 B/D.

2.2 Annual Energy Consumption

Based on data supplied to DOE by the American Petroleum Institute for the first half of 1977, estimated annual energy consumption by the U.S. petroleum refining industry for 1977 was as follows:

ESTIMATED 1977 ENERGY CONSUMPTION, SIC 2911

Energy Source	Consumption - 10^{12} Btu/yr
Crude Oil	6.0
Distillate Oil	27.0
Residual Oil	312.1
Liquefied Petroleum Gas	42.0
Natural Gas	768.2
Refinery Gas	1113.3
Petroleum Coke	456.1
Coal	18.0
Purchased Steam	36.0
Purchased Electricity[1]	75.8

This amounts to 537 thousand Btu/B of refinery input[1].

(1) Based on 3413 Btu/kWh for purchased electricity.

3.0 PROCESS ENERGY REQUIREMENTS

The subsections which follow will describe the energy consumed per barrel of refinery input, as well as providing detail on the type of energy required. A summary of the energy requirements per barrel of input appears in Exhibit 2911-7.

3.1 Unit Energy Consumption

Refinery energy requirements are generally supplied by a combination of the five following techniques:

	Major Uses
Electrical power	Rotating equipment
Steam	Process heat and rotating equipment
Hot oil	Process heat
Gas turbines/engined	Rotating equipment
Fired heaters	Process heat

There is considerable flexibility for substitution between power, steam and gas engines for driving rotating equipment, and the site philosophy adopted will be designed to optimize the balance between utility costs and reliability. The most commonly-found practice is to use steam or gas engine drivers for the major compressors and electric power for pumps, mixers, air coolers and miscellaneous services.

As indicated previously, estimated average energy consumption for the first half of 1977 was 537 thousand Btu/B of refinery input. Actual energy consumption will vary among individual refineries due to differences in age, degree of heat integration, size, and, most importantly, refinery complexity or process configuration. As an indication of the extent of such variation, statistics are provided in Exhibit 2911-8 on

variation in energy consumption of refiners reporting to API. Maximum, average, and minimum figures are shown for different size classes of refiners. While the data are presented in terms of refiner size class, the principal factor influencing energy consumption is process complexity. Energy consumption by process unit is indicated in Exhibit 2911-9 broken down by electricity, steam, and process heat.

3.2 Details of Electricity Consumption

(1) According to a recent Oil and Gas Journal article (June 21, 1976), approximately 92% of refinery electricity requirements are purchased with the remaining 8% generated on site. The same article indicates that even though refinery steam requirements are such that usually more electric power than needed would be generated if all refinery steam were expanded through turbines, self generated electricity has represented a declining trend in total refinery electric power requirements for many years. This is apparently due to the relatively low cost of purchased electricity until the last few years and the fact that most U.S. refineries were built many years ago when high pressure steam systems were not practical.

(2) Demand is essentially constant over the entire year. Typical capacity factors are on the order of 90%.

(3) Electricity is predominantly supplied as AC. DC is seldom used.

(4) Various voltages are used, typically 13 KV, 6 KV, and 400 V.

(5) Demand is essentially 50% fixed and 50% variable.

(6) There can be sudden variations in electrical demand. It is possible to have a single driver for a large machine (e.g. a catalytic reformer recycle gas compressor) taking one fifth of the total power consumption. Since starting current is 5 or 6 times the normal current, when this machine is placed online it draws a current equal to the total refinery need. Such a drain on the system causes a voltage dip which may then trip several other pumps. To combat this, the power supply must be capable of fast response and critical pumps may be fitted with automatic restart.

3.3 Details of Thermal Energy Consumption

(1) As indicated in Exhibit 2911-7, the principal mode of refinery energy consumption is by fired heaters to supply process heat. Steam and electricity account for lesser percentages of refinery energy consumption. There is relatively little direct use for hot water.

(2) Steam demand is essentially constant over the entire year, although space heating demand may cause a small increase during winter months.

(3) Principal steam system pressures in refineries range from about 200 to 600 psig. Some refineries operate a low pressure system at around 60-100 psig. A small amount of high pressure steam (700-1400 psig) is raised to generate electric (and shaft power) by turbine expansion and subsequently used in process applications.

(4) Moderate to high pressure steam is used primarily for shaft power in large compressors and pumps. Lower pressure steam is used primarily for steam stripping, vacuum condensation, smaller pumps and for heat exchange.

(5) Boilers are often sized to provide excess steam capacity to ensure steam availability for vital pumps, recirculation of tower bottoms and cooling and reflux in the event of a power failure.

(6) Steam is not only generated by the direct firing of fuels but through waste heat systems (Exhibit 2911-9).

(7) There are few refinery processes which use hot water directly. One is the desalting of crude oil: crude oil having greater than 15-20 lbs salt/1000 barrels of crude would cause excessive fouling of heat exchangers and towers. The salt is removed by washing with water at 200-300°F, heat to raise water to the proper temperature being provided indirectly via heat exchange systems from the combustion of fossil fuels.

(8) As indicated in more detail subsequently, most refinery processes are carried out at elevated temperatures. The use of high temperature process streams to preheat other streams is a common practice, with the degree of heat integration varying among refineries. Nevertheless, much low level heat is rejected by water and air cooling. A modern, efficient refinery would probably not view it economic to recover energy from process streams of less than about 180°F in temperature.

4.0 ANTICIPATED TRENDS

This section discusses the trends which are likely to occur in the industry through the year 2000. The major emphasis is on these areas: marketing, process technology, and energy consumption.

4.1 Refining Growth Trends

U.S. refining capacity grew at a rate of approximately 3.2% per year over the period 1950-1975[1]. In more recent years (1968 - 1977), U.S. refinery runs have increased at an average rate of 3.9% per year[2]. Projected future growth for the industry is at a much lower rate and is quite uncertain. Principal factors influencing U.S. refining growth through the year 2000 include:

(1) Availability and price of domestic and world oil. Some forecasts, such as that by the CIA, envisage severe supply demand pressures in the mid to latter 1980's. Others are more optimistic[3].

(2) Success of government efforts to promote development of alternate energy sources to substitute for oil. Some efforts such as coal and shale liquefaction, would, of course, also provide possible refinery inputs.

(3) Possible shift of refining to producing countries. The present entitlements program provides significant cost advantages for U.S. refining. It is likely that the spread between domestic and foreign oil prices will disappear between 1980 - 1985 and with it, (without government support in the form of tariffs or quotas) the present protection enjoyed by U.S. refiners.

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(1) International Petroleum Encylopedia 1977, p.303.

(2) Despite a temporary decline in 1974.

(3) Oil and Gas Journal, March 20, 1978, p. 39.

(4) Environmental regulations affecting future gasoline demand.

The 1977 National Energy Outlook projected an increase in U.S. refining runs by 1990 of about 1 - 1.5% per year[1]. A recent projection in the Oil and Gas Journal by Lichtblau[2] estimated U.S. oil demand growing at slightly less than 1% a year throughout the 1980's. Other recent industry projections have estimated growth in U.S. refining capacity over the period 1975 - 1990 at an average of 1.9% per year, with a slow down in growth in the latter 1980's[3]. For the purposes of this analysis, we estimate refining runs between now and 1985 to grow at an average rate of 1.5% a year and beyond that at 1% a year through 1990 and to level off in the 1990 - 2000 period. These projections, along with data on refinery runs since 1970, are illustrated in Exhibit 2911-10. They are probably conservative. An optimistic estimate would place 1990 U.S. refinery runs at approximately 19 million barrels per day.

4.2 Process Changes

The petroleum refining industry is a relatively mature industry in terms of technology. Future improvements are likely to be gradual in nature, such as in further catalyst development and modifications to existing designs, rather than in development of new processes.

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(1) Based on a review of PIES model runs.

(2) Oil & Gas Journal, March 27, 1978, p.86.

(3) Oil & Gas Journal, April 24, 1978, p.48.

Principal future changes in refinery process mix will be a reflection in large part of changing product demand such as for unleaded gasoline and low sulfur fuel oil.

There are two principal scenarios of the future U.S. refining process mix. The first is that, as a consequence of the expected leveling off in gasoline demand due to environmental regulations, cracking and octane improvement processes will decrease in relative importance in favor of distillate and fuel oil production. At the same time, there will be an increase in the importance of processes for the production of low sulfur fuel oil. The alternate scenario is that the future refinery will emphasize the production of gasoline, distillates, petrochemicals and specialty products. The logic behind this view is that gasoline and middle distillates are the refining products for which alternate fuels are not available in quantity, whereas heavy fuel oil can be potentially replaced by other energy sources such as coal. Both scenarios may be correct, with the first representative of conditions through the 1980's and the second taking on more relevance by the end of the century.

4.3 Implementation of New Technology

As indicated above, we anticipate technical improvements to be gradual in nature and to represent, for the most part, extensions of existing practice and design rather than the introduction of significant new processes.

4.4 Trends In Energy Requirements

The FEA "target" for the petroleum refining industry is an "adjusted" reduction of 20% in unit energy consumption by 1980 relative to 1972 conditions[1]. This was estimated to be equivalent to a net reduction of approximately 12% in actual unit energy consumption. Through the first half of 1977, the industry had achieved a net reduction of about 13%[2]. The pace of future reductions may slow down for the next several years, but we anticipate that further reductions in unit energy requirements of around 25% to be possible by 2000 for the same processing conditions. Assuming a significant increase in complexity by the end of the century, this might equate to a net reduction of around 10%. Exhibit 2911-11 presents estimates of future industry energy consumption.

With regard to the type of fuel used, we anticipate natural gas to be largely displaced as a refinery fuel by 1990 and to be initially replaced by oil. We also anticipate the use of coal, especially as a boiler fuel, to increase. We anticipate that coal will be the primary fuel used in new boilers but that there will be little conversion of existing boilers. By the year 2000, it is possible that gas from coal gasification will begin to substitute for oil as a refinery fuel to a significant degree. We would not expect it to be a significant source of energy earlier in the period, such as 1990.

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(1) Gordian Associates, An Energy Conservation Target for Industry SIC 29, FEA, June 25, 1976.

(2) Gordian Associates, Annual Report - Industrial Energy Efficiency Program, Draft, DOE, March 31, 1978.

Quantitative estimates of relative changes in refinery fuel mix are indicated below. These are very approximate figures:

	Relative Refinery Fuel Mix		
Fuel	1977	1985	2000
Oil	13	26	22
Gas	69	55	46
Coke	17	17	20
Coal	1	2	12

5.0 PLANT - SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements, including indications of load profiles, dtate conditions, and reliability considerations. Several plant factors are summarized in Exhibit 2911-12.

5.1 Load Profiles

Except for planned and emergency shutdowns (possibly two weeks a year) refineries operate at nearly constant rates of seven days a week, twenty-four hours a day. Due to the continuous nature of the processes involved, the need for steam coincides with the need for electric energy.

5.2 Operating Conditions

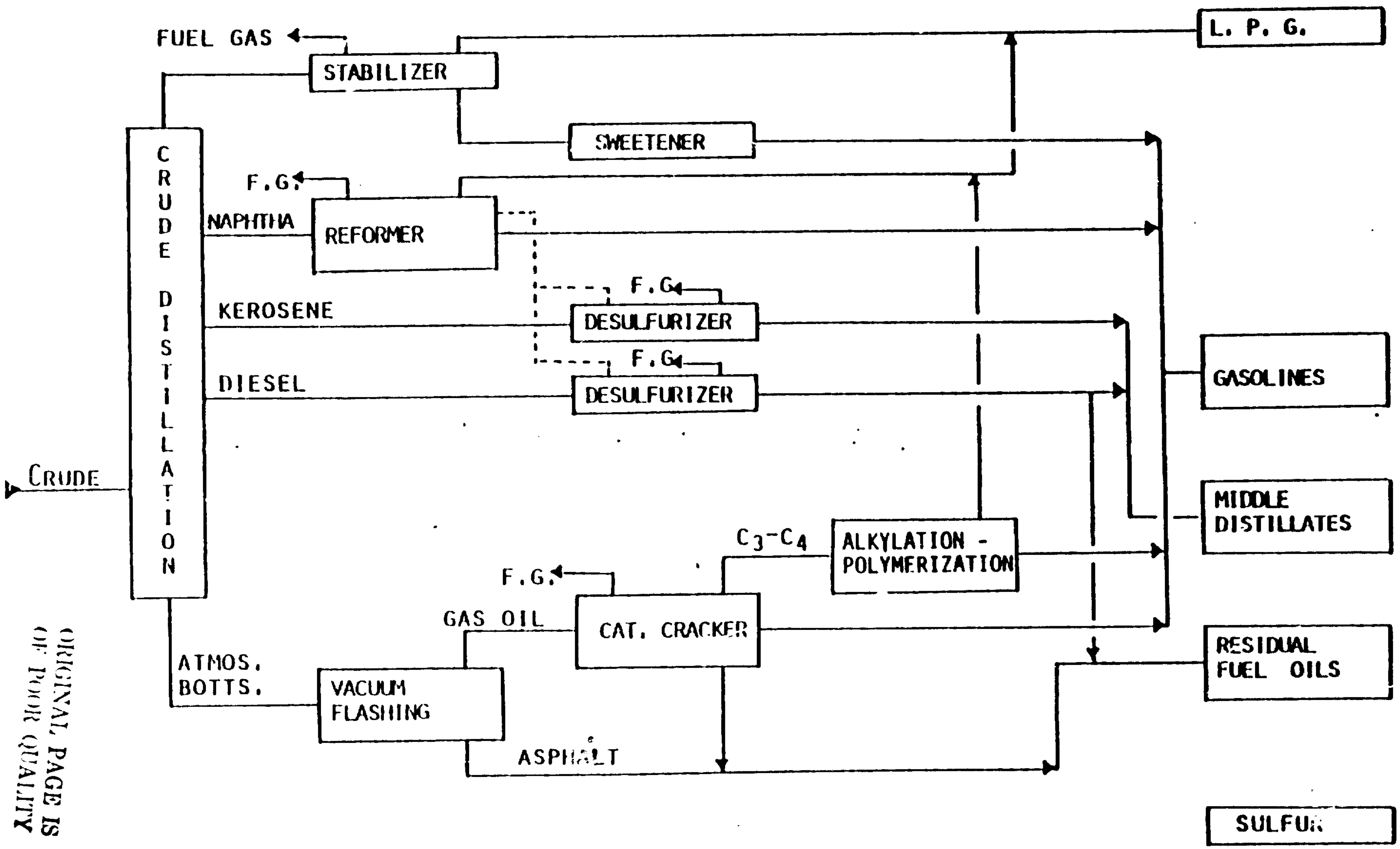
Since refinery configurations (mix and distribution of processes chosen) vary significantly among refineries, no single energy flow schematic is given. Data with regard to individual processes are provided in Exhibit 2911-13.

5.3 Reliability Considerations

Petroleum refining is a continuous, steady-state process in which flow rates, temperatures, pressures and levels are generally in balance at any time. A high degree of routine or continuous monitoring of conditions, using sophisticated instruments, is employed to assist in maintaining the balance. The loss of any utility supply immediately upsets the process balance. Loss of water to coolers and condensers results in pressure rise and venting of hydrocarbons to atmosphere or a safety system. Loss of electric power can upset the instrument controls and stop a large number of pumps with various undesirable consequences.

If any of the consequences cause loss of flow through furnace tubes or reactors, tube failures can result and catalyst beds may be ruined. Although a multitude of safety devices are incorporated into the design to ensure safe venting and orderly shutdowns, a risk of fire and/or explosion is always present. For these reasons, refiners take every action possible to ensure that utility supplies are dependable and particular emphasis is paid to electric power. As indicated previously, steam is often used as a back-up source of power for periods of electrical failure.

EXHIBIT 2911-1



TYPICAL REFINERY BLOCK FLOW DIAGRAM

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EXHIBIT 2911-2

Relative Process Distribution by Plant Size - January 1, 1977

Size Range MB/D	Vacuum Distillation	Thermal Operations	Cat Cracking	Cat Hydro Cracking	Cat Reforming	Cat Hydro Refining	Cat Hydro Treating	Alkylation	Aromatics/ Isomerization	Hydrogen	Coke	Asphalt	Lubes
0-1	.995	0	0	0	.017	0	0	0	0	0	0	4.232	0
1-2	0	3.339	0	0	.385	0	0	0	0	0	0	4.711	0
2-5	.965	1.091	.832	0	.845	0	.525	.920	0	0	0	2.581	7.141
5-10	.609	.928	.189	.307	.236	.170	.327	.081	0	.19	0	1.741	5.676
10-20	.409	.536	.323	.114	.403	.005	.310	.364	.089	0	.32	2.901	1.129
20-30	.671	.765	.731	.574	.738	.252	.643	.526	.493	0	.32	1.443	.223
30-50	.801	.469	.890	.333	.868	.465	.731	.955	.271	.41	1.36	1.508	.253
50-75	.889	1.161	1.098	.495	1.036	.966	.036	1.209	1.207	.39	.74	1.341	.228
75-100	.943	1.178	1.187	1.078	1.110	.871	1.424	1.705	.787	1.66	1.48	.413	.922
100-125	1.002	1.390	1.009	1.078	1.248	.549	1.229	1.003	1.644	2.09	1.54	.641	.414
125-175	1.143	1.473	1.147	.963	1.029	.717	1.309	.920	1.178	1.10	1.40	1.236	.816
175-225	1.060	.669	.763	.702	1.049	2.129	.736	1.115	1.407	.56	1.13	.623	0
225-300	1.121	1.405	1.176	1.553	.969	1.396	1.047	.932	.841	1.85	.45	.953	.805
300-400	1.219	.609	1.102	1.395	1.214	1.753	1.252	.929	1.000	.87	.68	.597	2.036
400-500	1.016	.951	.739	1.429	.653	1.081	.695	.454	.087	2.18	.90	.213	1.816
500+	1.097	1.066	1.109	.899	.752	0	.608	1.047	0	0	1.55	1.203	2.197

NOTES

(1) The numbers above are the ratio of the percent of capacity of each process in each size class to the percent of crude distillation capacity in that size class. Numbers greater than 1.0 indicate a disproportionate concentration of a process in a particular size category. The converse is true for numbers less than 1.0.

(2) Source: "Annual Refining Survey", Oil and Gas Journal, March 28, 1977.

EXHIBIT 2911-3

PRODUCT DISTRIBUTION - AS PERCENT OF TOTAL COMPANY DOLLAR SALES - BY REFINER SIZE - FOR JUNE, 1977

REFINER SIZE CATEGORY, MB/D

Product Description	0-10	10-30	30-50	50-75	75-125	125-175	175-250	250-500	500-900	900 +
Motor Gasoline										
Premium - Wholesale	3.25	2.96	2.75	2.23	2.58	3.84	7.42	3.81	3.30	3.13
Premium - DTW	0.31	1.46	0.09	0.18	1.03	0.62	5.35	0.55	3.75	6.67
Premium - Retail	2.16	2.40	2.07	1.60	4.77	0.49	1.02	1.95	0.71	0.75
Regular - Wholesale	9.76	11.57	14.19	11.95	10.86	25.78	24.48	27.10	12.93	13.04
Regular - DTW	3.47	2.56	0.93	1.41	9.82	5.89	2.20	1.87	7.39	14.62
Regular - Retail	8.67	8.31	7.20	6.55	17.65	2.00	2.69	7.71	5.11	1.55
No-Lead - Wholesale	1.56	2.40	4.12	2.83	3.25	7.66	9.00	7.51	5.80	4.00
No-Lead - DTW	1.44	0.96	0.44	0.46	2.65	1.33	3.75	0.74	5.76	8.93
No-Lead - Retail	2.10	2.81	3.01	2.03	7.39	0.80	0.89	2.90	2.35	1.15
Total Motor Gasoline	33.32	35.73	34.80	29.24	60.01	51.41	56.80	54.14	47.11	53.35
Distillate										
#1 Diesel Fuel - Wholesale	0.01	1.41	0.00	0.13	0.06	0.06	0.06	0.03	0.25	0.30
#1 Diesel Fuel - Retail	0.06	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.01
#2 Diesel Fuel - Wholesale	4.74	4.38	5.46	3.56	6.19	19.74	8.79	4.86	3.90	8.41
#2 Diesel Fuel - Retail	1.53	0.40	0.45	2.00	0.31	0.00	0.36	0.17	0.43	0.29
#1 Heating Oil - Wholesale	0.06	0.22	0.72	0.70	0.16	0.05	0.07	0.15	0.21	0.19
#1 Heating Oil - Retail	0.04	0.00	0.04	0.00	0.00	0.02	0.01	0.01	0.04	0.00
#2 Heating Oil - Wholesale	1.99	3.07	6.09	6.01	7.21	11.16	6.83	8.03	6.74	5.97
#2 Heating Oil - Retail	0.45	1.38	0.29	2.77	0.70	0.25	0.11	0.08	0.46	0.25
All Other Middle Distillates	2.35	1.90	3.99	1.03	0.00	0.50	0.51	1.21	2.65	0.68
Total Distillate	11.23	12.76	17.04	16.31	14.53	31.78	16.74	14.55	14.68	16.10
Residual Fuel Oil										
#5 Residual Fuel Oil - Wholesale	2.58	2.84	4.72	0.02	0.00	0.04	0.00	0.06	0.01	0.10
#5 Residual Fuel Oil - Retail	0.37	0.73	3.27	0.04	0.00	0.05	0.04	0.38	0.08	0.12
#6 (<.3% S) - Wholesale	3.86	5.81	3.35	4.27	5.58	0.00	3.60	1.43	0.01	1.04
#6 (<.3% S) - Retail	0.61	2.70	0.00	12.70	0.00	0.00	0.01	0.00	12.98	5.92
#6 (.3 - 1% S) - Wholesale	11.70	2.60	0.00	2.32	6.48	1.37	2.40	5.03	1.37	0.48
#6 (.3 - 1% S) - Retail	1.35	5.15	0.00	2.90	3.26	3.05	0.57	2.57	5.30	2.80
#6 (>1.% S) - Wholesale	8.13	4.08	0.47	2.13	1.35	3.12	2.62	0.69	1.39	1.91
#6 (>1.% S) - Retail	1.12	6.53	1.34	1.09	0.90	1.73	0.00	4.11	3.41	2.19
Bunker C - Wholesale	11.38	2.70	2.57	13.12	0.00	0.49	3.70	0.28	0.00	0.13
Bunker C - Retail	2.27	0.00	0.00	0.17	0.00	0.00	0.54	0.13	0.50	0.34
Total Residual	43.37	33.14	16.22	38.76	17.57	10.35	13.48	15.28	25.56	15.03
Aviation Fuels										
Gasoline - Wholesale	0.00	0.00	0.00	0.07	0.00	0.00	0.03	0.57	0.09	0.29
Gasoline - Retail	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.13	0.12	0.25
Naphtha Type - Wholesale	3.42	1.46	6.94	0.96	0.00	0.00	1.77	0.81	0.93	0.00
Naphtha Type - Retail	2.23	8.55	4.64	1.47	0.00	0.00	1.36	1.17	4.94	1.36
Kerosene Type - Wholesale	0.00	0.66	0.00	1.75	2.55	0.00	4.43	0.57	0.11	0.25
Kerosene Type - Retail	0.00	1.80	4.66	1.49	0.00	0.01	0.00	3.36	2.55	7.25
Total Aviation Fuel	5.65	12.47	16.24	5.76	2.55	0.02	7.59	6.61	8.74	9.41
Kerosene										
Kerosene - Wholesale	0.76	0.64	1.15	0.30	0.73	1.31	0.20	0.21	0.20	0.22
Kerosene - Retail	0.00	0.01	0.66	0.12	0.00	0.29	0.00	0.00	0.14	0.04
Total Kerosene	0.76	0.65	1.81	0.42	0.73	1.60	0.20	0.21	0.34	0.27
Petrochemical Feedstocks	1.30	0.76	10.38	8.48	2.18	2.92	1.75	1.31	1.17	1.73
Liquefied Petroleum Gas	4.33	4.49	3.49	0.95	2.35	1.93	3.44	7.39	2.41	3.57

NOTES

1. Above figures are based on data reported to FEA on P-302 forms for the month of June, 1977.
2. Above data are percent of sector dollar sales. Product sales distribution data in Appendix Q and in Exhibit 3.3 are in volume rather than dollar percent.
3. The abbreviation DTW stands for dealer tank wagon.

EXHIBIT 2911-4

ESTIMATED ANNUAL NATIONAL DATA (1977), PETROLEUM REFINING INDUSTRY[1]

Refinery Input Million B/D	Total Energy Consumption Trillion Btu	Purchased Electricity Trillion Btu	Purchased Fuels Trillion Btu	Coal	Oil	Gas	Other	Total Energy Consumption for SIC 2911 Trillion Btu	Recent Total Energy Consumption Represented
14.561	2854.8	75.8[2]	(3)	18.0	345.1	1923.5	510.1	2854.8	100.0

(1) Energy consumption data based on statistics reported for first half of 1977 by API to DOE extrapolated for full year.

(2) Purchased electricity converted to Btu at 3413 Btu/kWh.

(3) API does not specifically break out purchased fuels.

EXHIBIT 2911-5

Distribution Of Companies In The U.S. Petroleum

Refining Industry By Size 1970-1977

	Operating Capacity (MB/D)						Number of Companies					
Size	1970	1972	1974	1975	1976	1977	1970	1972	1974	1975	1976	1977
0-1	6.8	4.2	7.6	4.8	3.4	6.6	10	7	11	8	5	11
1-2	11.9	13.6	10.9	10.9	11.5	4.5	8	8	7	7	7	3
2-5	105.7	82.2	70.9	82.0	86.0	95.5	31	24	23	22	23	26
5-10	106.5	99.7	96.3	111.6	114.7	145.7	14	13	13	14	14	18
10-20	287.4	330.3	329.6	320.2	333.2	373.2	20	23	22	19	21	24
20-30	209.0	267.0	263.4	394.3	383.0	343.0	8	10	10	15	15	14
30-50	453.7	314.5	413.6	408.6	400.6	405.6	11	8	10	10	10	12
50-75	247.0	253.0	360.2	504.8	481.3	671.3	4	4	6	8	8	11
75-100	439.0	446.4	378.9	272.9	520.7	263.1	5	5	4	3	6	3
100-125	229.5	213.0	320.0	320.8	372.7	125.0	2	2	3	3	3	1
125-175	302.5	272.0	432.9	455.7	149.7	341.2	2	2	3	3	1	3
175-225	205.0	412.0	413.7	631.7	823.1	829.2	1	2	2	3	4	4
225-300	769.8	201.0	260.0	260.0	268.0	760.3	3	1	1	1	1	3
300-400	1,031.9	1,060.9	1,431.0	1,063.9	1,471.4	1,074.4	3	3	4	3	4	3
400-500	451.2	1,335.9	1,374.7	1,019.0	1,404.0	1,423.0	1	3	3	4	3	3
500+	6,974.7	7,649.3	8,039.9	8,027.5	8,042.0	8,879.3	8	8	8	8	8	9
Total	11,082.4	13,034.8	14,220.3	14,696.8	14,067.5	15,870.9	131	123	130	131	133	148

Source: U.S. Bureau of Mines Annual Refining Survey

EXHIBIT 2911-6

Distribution of Operating Capacity-By Plant Size

In the U.S. Petroleum Refining Industry

January 1, 1977

Size Range MB/D	Capacity B/D	Percent of Total Capacity	Number of Plants	Percent of Total Plants
0-1	2590	.0	7	2.8
1-2	9500	.1	8	2.9
2-5	102400	.6	31	11.3
5-10	255112	1.6	38	13.9
10-20	447090	2.8	33	12.0
20-30	638710	4.0	27	9.9
30-50	1458409	9.2	36	13.1
50-75	1819193	11.5	30	10.9
75-100	1414131	8.9	16	5.8
100-125	1112500	7.0	10	3.6
125-175	2144300	13.5	15	5.5
175-225	1325900	8.4	7	2.6
225-300	1870000	11.8	7	2.6
300-400	2761100	17.4	8	2.9
400-500	0	0.0	0	0.0
500+	510000	3.2	1	.4
TOTAL	15870935	100.0	274	100.0

Source: U.S. Bureau of Mines Annual Refining Survey

EXHIBIT 2911-7

ESTIMATED ENERGY CONSUMPTION PER INPUT BARREL IN PETROLEUM REFINING - 1977[1]

Electricity Thousand Btu Per Barrel	Hot Water Million Btu Per Barrel	To 300°F	300-500°F	Over 500°F	Direct Fuel Thousand Btu Per Barrel	Exhaust Stream Temperature °F	Exhaust Stream Energy Million Btu Per Barrel
14.3[2]	negligible	negligible	99	(3)	424	--	--

Notes

(1) The above figures are estimated averages. There is significant variation in total energy consumed and in the form in which it is consumed among refineries - see Exhibits 2911-8 and 2911-9.

(2) Electrical energy converted to Btu at 3413 Btu/kWh. Above figure is for purchased electricity only to avoid double counting. A recent Oil and Gas Journal article (June 21, 1976) estimated purchased electricity to account for 92% of refinery electric energy requirements.

(3) A small amount of high pressure steam (700 - 1400 psi) is generated in some refineries for power generation before use as process steam.

EXHIBIT 29I1-8

RATIO OF REFINER UNIT ENERGY CONSUMPTION TO AVERAGE FOR API REPORTING SAMPLE FOR FIRST HALF OF 1977

Refiner Size Range MB/D	Class Minimum	Class Average	Class Maximum
>500	0.92	1.01	1.18
200 - 500	0.75	0.97	1.34
100 - 200	0.59	0.98	1.64
50 - 100	0.49	0.96	1.43
30 - 50	0.69	0.99	1.33
<30	0.48	1.09	2.55

Source: Letter dated October 12, 1977 from Mr. Ray Wright of API to Mr. Tyler Williams of DOE.

EXHIBIT 2911-9

ENERGY REQUIREMENTS FOR MAJOR REFINERY PROCESSES

Process	Energy Used per Bbl of Process Charge		
	Steam lbs	Direct Fired Heaters M Btu	Electricity kWh
Crude Distillation	5-46	81-238	0.17-1.71
Vacuum Flash	5-50	72-134	0.2 -1.5
Thermal Cracking	0-50	300-940	0.8 -5.8
Visbreaking	4-80	138-350	0.3 -1.8
Delayed Coking	(12)-49	285-625	0.3 -3.1
Fluid Catalytic Cracking	(8)-240	0-470	0.1 -12
Catalytic Reforming	(6)-128	220-680	0.3 -6
Hydrocracking	0-28	130-830	3.5-15
Hydrotreating	0-50	0-282	0.35-2.6
Butane Isomerization	17-627	39-500	1.2 -4.9
Polymerization	0-343	0-750	0 -11.4
Alkylation	0-1,000	0-1440	2.7-8.8
Hydrogen Production/MSCF	0-335	0-430	0.4-5.7

Notes

(1) Parentheses indicate net steam generation.

(2) Direct fired heat for catalytic cracking does not include 179-353 MBtu/B in combustion of coke.

(3) Above data from Oil and Gas Journal, October 31, 1977.

(4) An efficiency of 75% was assumed between process heat absorbed numbers given in OGJ article and actual heat of combustion.

EXHIBIT 2911-10

HISTORICAL AND PROJECTED U.S. REFINERY RUNS, 1970 - 2000

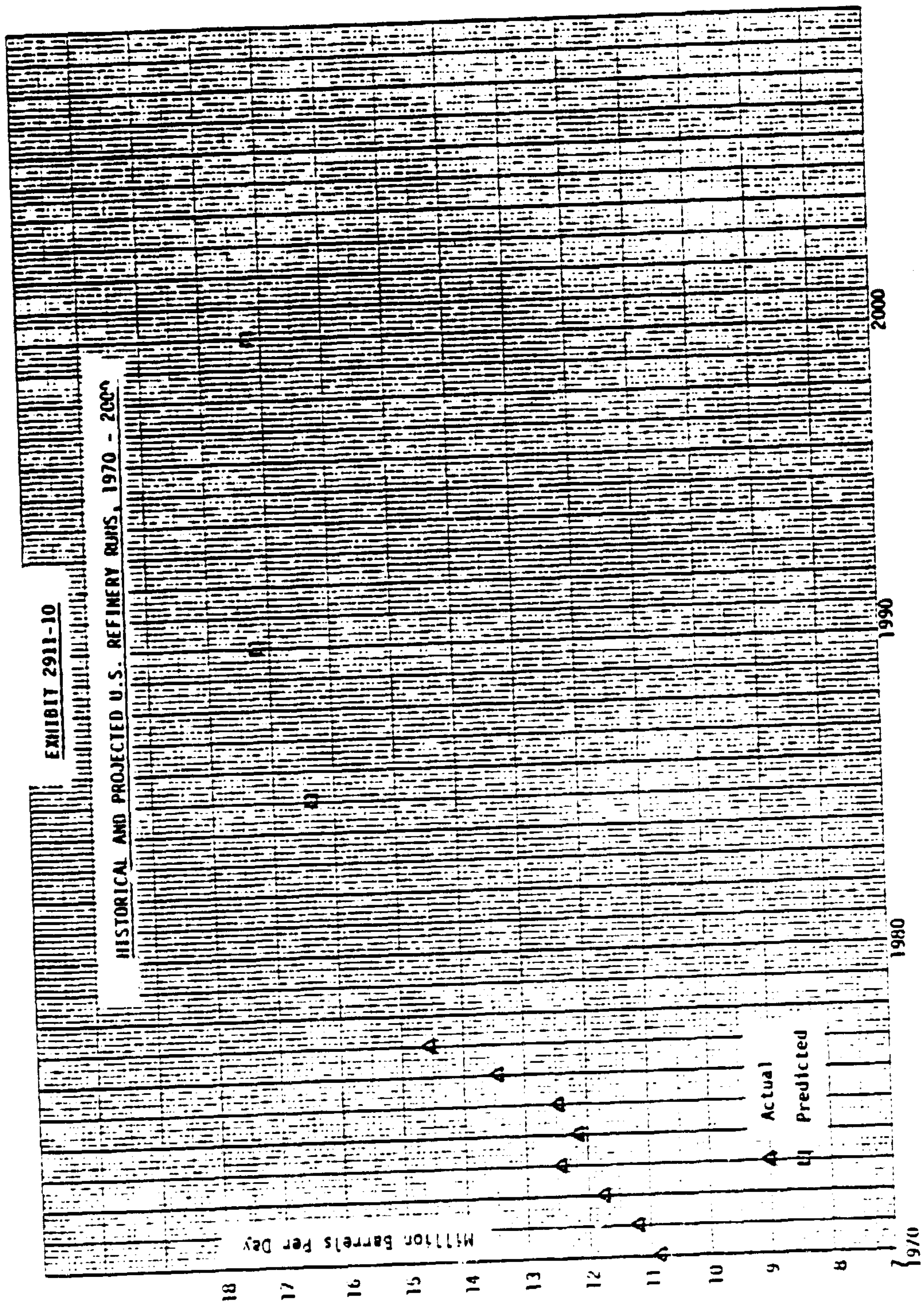

EXHIBIT 2911-11

ESTIMATED ANNUAL ENERGY CONSUMPTION IN PETROLEUM REFINING FOR SELECTED YEARS

	1977[1] (Base Year)	1985[3]	2000[4]
	(all data in Btu x 10^{12})		
Fuel	2779	2970	2958
Purchased Electricity[2]	75.8	83	83

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1 From Exhibit 2911-4.

2 Electricity converted to Btus at 3413 Btu/kWh. Projections of purchased electricity do not take into account possible increase in on-site generation.

3 Data for 1985 based on the following assumptions:

(a) total refinery input as shown in Exhibit 2911-10.

(b) unit energy consumption of 510 M Btu/B.

4 Data for 1985 based on the following assumptions:

(a) total refinery input as shown in Exhibit 2911-10.

(b) unit energy consumption of 483 M Btu/B.

EXHIBIT 2911-12

PETROLEUM REFINERY PLANT FACTORS

Typical Plant Capacity B/D	Plant Size Range B/D	Electric Load Factor	Thermal Electric Coincidence Factor	Projected Applicability to 2000
150,000	100,000	0.95	1.0	*
	700,000			

* The typical (capacity weighted average) size plant in this time period will be in the range of 150,000 - 200,000 B/D.

EXHIBIT 2911-13

APPROXIMATE OPERATING CONDITIONS FOR PRINCIPAL REFINERY PROCESSES

Process	Common Feedstock Boiling Range	Operating Conditions[1] PSIA	Operating Conditions[1] Temperature, °F
Atmospheric Distillation	Crude oil	15	600-700
Vacuum Flash	650°+	0.5-1	725-775
Thermal Cracking	650°+/650-1050°	300-700[2]	880-950
Visbreaking	1050°+	230-250[2]	860-890
Coking	650°+/650-1050°	300-500[2]	890-960
Fluid Catalytic Cracking	650-1050°	17-30	860-950
Catalytic Reforming	200-380°	100-500	850-970
Hydrotreating	(3)	365-415	475-600
Butane Isomerization	normal butane	200-350	100-210
Polymerization[4]	cracking-still gases/isobutane	300-600	300-450
Alkylation[5]	iso and normal butane	100-150	70-115

1 In main reaction.
2 Back pressures in pipestill heaters.
3 Variety rates, e.g.: 200-380/380-525°/525-650°.
4 For phosphoric acid polymerization.
5 For HF alkylation.

Sources: Nelson, W.L., Petroleum Refining Engineering, McGraw Hill, p.p. 700-701, 4th ed. and estimates by Gordian Associates.

TIRES

1.0 PROCESS IDENTIFICATION

This section identifies the standard industrial classification for the tire industry and provides a description of its manufacturing processes.

1.1 SIC Classification

The production of tires and inner tubes for all types of vehicles, airplanes, and farm equipment is classified under SIC code 3011, "Tires and Inner Tubes". Other products classified under SIC 3011 are tire repair and retreading materials; however, establishments primarily engaged in retreading tires are classified under SIC 7534.

1.2 Process Description

Tire manufacture involves four major process steps (Exhibit 3011-1).

1) raw material compounding
2) fabrication of tire components (i.e., tread, sidewall, fabric belts, tire bead, etc.)
3) tire building
4) tire molding and curing

Raw material compounding recipes are typically a combination of synthetic and natural rubber (including reclaimed rubber), carbon black, processing aids (softeners), pigments, vulcanization agents and accelerators, and age resistors (antioxidants). The relative amounts of each raw material vary depending on the product end use and tire component (i.e., tread, sidewall, etc.). Rubber and carbon black are estimated to range between 40% to 65% and 20% to 30% of the total raw material, respectively.

The compounding (intimate mixing) operation is typically performed by a Banbury mixer.* (Exhibit 3011-2). The Banbury mixer consists of a completely enclosed chamber in which two spiral rotors operate, revolving in opposite directions and at slightly different speeds thereby subjecting the stock to shear and uniformly blending all ingredients. The rubber is charged directly into the mixing chamber and a ram is lowered to exert pressure on the batch. (Water or steam may be circulated in the hollow rotors and the walls of the mixing chamber.) After the desired mixing time, the batch is discharged onto a roll mill where the rubber is sheeted out.[1]

The subsequent sheeting out operation is performed by several roll mills* arranged in series. In this arrangement, the rubber compound is initially blended with more additives and finally cooled. It is then slabbed off for use later in other operations.[1]

Prior to the tire building step, the basic components of the tire are fabricated (i.e., fabric belts or plies, tire bead, chafer, tread, sidewall and inner liner (as shown in Exhibit 3011-3).

The fabric belts are made of rayon, nylon, polyester, fiberglass, steel, or aramid fiber tire cord. The tire cord is arranged in the warp** direction and lightly woven with cotton thread as the filling***.

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* Roll mills are also used, for rubber compounding, although to a lesser degree than Banbury mixers. The roll mill consists of two parallel, horizontal rolls rotating in opposite direction and at slightly different speeds. The mixing takes place at the nip as the rubber is fed to and pulled through the nip. The rubber is recirculated and after the desired mixing time, cut off the rolls.

** Warp - the yarns that run lengthwise in a woven fabric.

*** Filling - the yarns that run widthwise (crosswise) in a woven fabric.

The filling is woven just enough to hold the warp threads together. The woven fabric is dipped into a bath of adhesive solution and then dried in an oven. The adhesive is needed to bond the fabric to the rubber stock. The dipped fabric is bonded or calendered between two thin sheets of unvulcanized rubber called skim stock. Calendering is done by pulling the fabric, simultaneously with the skim stock, through the nip of two or more parallel rolls. The pressure exerted by the calender rolls at the nip bonds the fabric and skim stock together. A calendering arrangement is shown in Exhibit 3011-4.

After calendering, the ply fabric is laid out flat and cut to the proper size and shape for the particular tire being built (i.e., radial or bias ply). For radial and bias ply tires, the ply fabric is cut at angles of 90° and 30° to the direction of the warp cords, respectively (Exhibit 3011-5). When the ply fabric is ready to be built into the tire it will be turned to run circumferentially around the tire. The warp cords will run straight across the tread for radial tires and at an angle to the tread for bias ply tires (Exhibit 3011-5). The ply fabric adds strength and road handling control to the tire.

The tire bead is a multi-strand high tensile steel loop insulated with a hard rubber compound which will adhere firmly after vulcanization. The bead wire is rubber coated on a coating machine and then wound into loops on another machine.

The tread is the wearing surface of a tire. It is applied as an extruded strip which after vulcanization must exhibit maximum resistance to abrasion, tearing, cracking, chipping, weathering, and heat aging. The sidewall has the same function and requirements as the tread but

c-6

the degree to which it must meet these requirements is not necessarily the same. In some cases, the tread and side wall are extruded from the same stock as a single unit from an extruder.* In other cases, for reasons of economy or differing service requirements, different stock for tread and sidewall may be used. In these cases, the tread and sidewall may also be applied as a single unit. This is accomplished by properly spacing and joining the two stocks in a double barreled extruder, or by plying a cap of extruded tread stock on top and in the center of an extruded base of sidewall stock.

The inner liner is the air retaining layer applied first (innermost) in tubeless tires. (Butyl rubber is commonly used because of its outstanding resistance to passage of air and thermal oxidation.) The inner liner is an integral part of the tire, applied as a calendered sheet. It bonds to the first fabric layer of the tire body during vulcanization.

In the tire building operation, the tire components are assembled to form a pre-vulcanized, pre-molded, "green" tire. The tire is built on a collapsible, rotatable steel drum. By virtue of the pre-vulcanized rubber's "tack", the tire components are combined or cemented together in the proper structure. First, the inner liner is wrapped around the tire building drum and its ends are spliced together. Similarily, the ply fabrics are wrapped around the drum, on top of the inner liner. For a bias ply tire, two plies are applied circumferentially, one on top of

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* In industry, the sidewall and tread extruder is refered to as a "tuber". Shapeless compounded rubber is extruded into an irregular form to be applied to the uncured or "green" tire body or "carcass" in the tire building operation.

the other, with opposing or crossing warp cord direction. The previously assembled tire beads are applied, one on each end, and the fabric plies are folded over and around them. For a four-ply tire, two additional belt plies are applied and folded over the bead assembly. As before with the bias-ply tire, these belts have alternating warp cord direction. The radial tire also utilizes belts in the tread region to stiffen that area. The chafer is applied to the bead followed by the extruded tread and sidewall section, which has been cut to the correct length and formed into a band. The "green" tire is now ready for shaping and curing (vulcanization).

Tire curing and shaping is necessary to remove rubber tackiness, add strength, shape the tire to fit a wheel, and give it a particular tread design. Bias-ply and radial tire curing and shaping differ slightly from each other in process handling and/or equipment. The green bias-ply tire is shaped like an oil drum while the green radial tire is preformed during construction and requires little additional shaping with the exception of forming tread design and other moldings only(i.e., sidewall lettering); however, both types must be cured.

The equipment used for bias-ply tire curing and shaping is called a tire curing press. The curing press has two half-molds, each of which forms one half of the shape of the tire. An inflatable rubber bladder rests in the center of the bottom mold. The green tire is put over the bladder. Steam pressure inflates the bladder and forces the tire to expand. As the green tire expands to mold size, the mold closes around it simultaneously. Heat and increased pressure, applied by the mold and steam inside the bladder, softens the green tire and causes it to fill

the design of the mold while, at the same time, vulcanizing the rubber. After 15 to 20 minutes for a typical four-ply tire, the tire is removed from the mold. The hot tire is immediately mounted on a rim and inflated to maintain its shape while cooling (i.e., prohibit shrinking of the rubber and cord).

Radial tire curing, may use the same doughnut mold as a bias-ply or, as in some processes, a segmented mold. When using the doughnut mold, the preformed tire is inflated to a slightly smaller size than the mold for ease of removal after curing. The tire is shaped for tread design and other moldings (i.e., sidewall lettering) and to set the beads in proper position. A segmented mold is similar to a doughnut shaped mold which has been divided into several parts (usually eight segments, in some cases top only or top and bottom). As before, a steam filled bladder inflates the tire and the segments are closed around it. When curing is completed the segments are pulled away and the tire is removed. Segmented molds make tire removal easier than from doughnut shaped molds.

2.0 NATIONAL DATA

The annual national data for tire production is presented in this section. A summary of energy consumption and production is shown in Exhibit 3011-6.

2.1 Production Data

Summarized below is the total U.S. production of all types of tires from 1974 through 1977.

PRODUCTION*

(thousands of tires)

	1974	1975	1976	1977
Passenger Car Tires	175,160	157,680	156,476	193,439
Truck and Bus Tires	35,727	28,611	31,021	40,002
Motorcycle Tires	502	414	456	588
Farm Tractor Tires	6,853	5,294	4,948	5,411
Aircraft Tires	676	567	604	663
Industrial Pneumatic Tires	6,660	4,173	5,122	5,566
Garden Tractor Tires	2,661	1,213	2,378	2,053
Total Tires	228,239	197,952	201,005	247,722
% Radial Tires** of passenger car tires	28%	38%	40%	43%
% Passenger Car Tires of total tires	77%	80%	78%	78%

* Source: Rubber Manufacturers Association, Washington, D.C.
** Derived from sources 2, 3, 4, and 5.

Tire manufacturing plants typically operate 24 hours per day, 5 days per week with tire production ranging from 20 MM lbs. per year to 350 MM lbs. per year.(6) Production from a typical tire plant is estimated at 200 MM lbs. per year.(6)

The following companies contribute to the total U.S. tire production.

Estimated Tire Production by Plant*(2)

(thousands of tires per day)

Company	Plant Location	Passenger Tires	All Other Tires	Total Tires
Armstrong	Des Moines, Iowa	11.0	3.5	14.5
	Hanford, Calif.	11.0	-	11.0
	Natchez, Miss.	8.0	5.5	13.5
	West Haven Conn.	12.0	-	12.0
	Nashville, Tenn.	8.5	9.0	17.5
	Total	50.5	18.0	68.5
Carlisle	Carlisle, Pa.	-	16.0	16.0
Cooper	Findlay, Ohio	8.4	5.0	13.4
	Texarkana. Ark.	16.6	2.0	18.6
	Total	25.0	7.0	32.0
Denman	Warren, Ohio	1.5	2.0	3.5
Dunlop	Buffalo, N.Y.	11.1	5.1	16.2
	Huntsville, Ala.	14.0	-	14.0
	Total	25.1	5.1	30.2
Firestone	Akron, Ohio	16.0	4.5	20.5
	Albany, Ga	24.0	1.0	25.0
	Bloomington, Ill.	-	.1	.1
	Decautur, Ill.	21.5	2.9	24.4
	Des Moines, Iowa	16.0	3.5	19.5
	Los Angeles, Calif.	8.3	2.0	10.3
	Memphis, Tenn.	15.5	7.0	22.5
	Nashville, Tenn.	-	1.5	1.5
	Pottstown, Pa	21.5	2.0	23.5
	Salinas, Calif.	12.5	2.4	14.9
	Wilson, N.C.	15.0	-	15.0
	Total	150.3	26.9	177.2
Firestone Subsidiaries				
Dayton	Dayton, Ohio	10.0	7.0	17.0
	Oklahoma City, Okla.	20.0	2.0	22.0
Seiberling	Barberton, Ohio	8.0	2.5	10.5
	Total	38.0	11.5	49.5

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Company	Plant Location	Passenger Tires	All Other Tires	Total Tires
General	Akron, Ohio	-	8.5	8.5
	Bryan, Ohio	-	.1	.1
	Charlotte, N.C.	17.0	-	17.0
	Mayfield, Ky.	25.0	9.0	34.0
	Waco, Texas	15.7	5.3	21.0
	Mt. Vernon, Ill.	9.9	.1	10.0
	Total	67.6	23.0	90.6
BF Goodrich	Akron, Ohio	-	.5	.5
	Ft. Wayne, Ind.	18.4	6.1	24.5
	Miami, Okla	5.6	7.0	12.6
	Oaks, Pa.	18.0	1.0	19.0
	Tuscaloosa, Ala.	30.0	-	30.0
	Total	72.0	14.6	86.6
Goodyear	Akron, Ohio	10.0	11.0	21.0
	Danville, Va.	-	7.0	7.0
	Gadsden, Ala	26.5	13.5	40.0
	Jackson, Mich	21.0	3.5	24.5
	Los Angeles, Calif	-	5.0	5.0
	Topeka, Kans	23.0	5.5	28.5
	Union City, Tenn.	38.0	-	38.0
	Lawton, Okla (on stream in 1978)	-	-	-
	Total	118.5	45.5	164.0
Goodyear Subsidiaries Kelly-Springfield				
	Cumberland, Md.	10.5	8.5	19.0
	Freeport, Ill.	14.5	5.0	19.5
	Tyler, Texas	25.0	-	25.0
	Fayetteville, N.C.	34.0	.5	34.5
	Total	84.0	14.0	98.0
Lee	Conshohocken, Pa.	13.0	-	13.0
I.R.I.	Louisville, Ky.	.6	-	.6
Mansfield	Mansfield, Ohio (is being closed)	7.5	4.5	12.0
	Tupelo, Miss. (closed temporarily now open)	-	-	-
	Total	-	4.5	12.0

Company	Plant Location	Passenger Tires	All Other Tires	Total Tires
McCreary	Indiana, Pa.	2.5	2.5	5.0
Michelin	Greenville, S.C.	20.0	-	20.0
	Spartanburg, S.C. (on stream in 1978)	-	-	-
	Dothan, Ala. (on stream in 1978)	-	-	-
	Total	20.0	-	20.0
Mohawk	Akron, Ohio	-	2.1	2.1
	West Helena, Ark.	9.5	.5	10.0
	Salem, Va.	13.0	.5	13.5
	Total	22.5	3.1	25.6
Uniroyal**	Chicopee Falls, Mass.	22.5	4.0	26.5
	Detroit, Mich.	14.0	2.0	16.0
	Eau Clair, Wisc.	17.5	7.0	24.5
	Los Angeles, Calif.**	8.0	2.5	10.5
	Opelika, Ala.	14.0	3.0	17.0
	Ardmore, Okla.	32.0	-	32.0
	Total	108.0	18.5	126.5
	GRAND TOTAL	806.6	212.2	1018.8

* Estimated tire production by plant as of January 1, 1978

** Uniroyal bias tire plant at Los Angeles, California was shut down permanently in March, 1973.(6)

2.2 Annual Energy Consumption

The U. S. Census Bureau reports the following energy consumption by fuel type for SIC 3011 in 1975 (7):

1975 Annual Energy Consumption, SIC 3011

Energy Source	Consumption (x 10^{12} Btu)
Fuel Oil	19.88
Coal	13.09
Natural Gas	26.62
Other*	1.00
Purchased Fuel (Total)	60.59
Purchased Electricity**	15.52
Purchased Fuels and Electric Energy (Grand Total)	76.11

* "Other" includes "Fuels not specified by kind".(7)
** Purchased Electricity converted at 3413 Btu/kWh.

The annual energy consumed by tire manufacture was determined by utilizing an overall total energy requirement of 15.76 MM Btu/ton comprised of 12.04 and 3.72 MM Btu/ton of fuel and electricity*, respectively. (6) Since tire production is commonly reported by number of tires produced and tire weight is highly varied depending on the size and type of tire, tire production by weight was not available.

* Electricity converted at 3413 Btu/kWh.

However, on the basis that 63.5% of all new rubber (synthetic and natural) was consumed by the tire industry in 1975*[8] and approximately 45% of a typical tire is rubber,[9] the total weight of tires produced and hence, total energy consumed by their production in 1975 was estimated.**

1975 Annual Energy Consumption, Tires

Energy Source	Consumption ($\times 10^{12}$ Btu)
Fuel Oil*	15.45
Cost*	10.17
Natural Gas*	20.68
Other*	0.78
Purchased Fuel (Total)*	47.08
Electricity**	14.54
Purchased Fuel and Electric Energy (Grand Total)	61.62

* Purchased fuel was distributed across the various fuel types proportionately with the 1975 Census of Manufactures data.

** Electricity converted at 3413 Btu/kWh.

The total energy consumed by the tire industry is therefore estimated to represent 81% of that consumed by SIC 3011 as a whole. The remaining 19% may be attributed to the manufacture of inner tubes, retreading materials, and other related or ancillary products also classified under SIC 3011.

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* In 1975, the consumption of all new rubber by all (8) industry sectors (tire and non-tire) was $2,769 \times 10^3$ tons.

** This method assumes that on-plant stockpiled rubber inventory was not consumed.

3.0 PROCESS ENERGY REQUIREMENTS

The following sub-sections describe the thermal and electrical energy requirements per unit of production in tire manufacture. A summary of the energy requirements per unit output is presented in Exhibit 3011-7.

3.1 Unit Energy Consumption Data

Tire production is an energy intensive manufacturing operation with a diversity of end products ranging from passenger car tires weighing between 20 and 40 pounds to earthmover tires weighing up to 6,000 pounds each. For the production of all types of tires, the following energy requirements are representative of industry overall.[6]

Unit Energy Requirements

Tire Manufacture

	MM Btu/Ton
Fuel*	12.04
Electricity**	3.72
Total	15.76

* Fuel is used primarily to raise steam (less than one percent of the total energy is used as direct fuel).[6] Assuming a boiler efficiency of 80%, approximately 8000 lbs. of steam at 250 psig are used per ton of tires produced.

** Converted at 3413 Btu/kWh.

3.2 Details of Energy Consumption

Tire manufacturing plants operate continuously, 24 hours per day, for typically 5 days per week. The manufacturing process uses mostly electricity and steam with usually less than 1% of the total energy consumed as direct fuel.[6]

Electricity is primarily used by the electro-mechanical operations prior to tire building. Such electric energy intensive operations are: rubber compounding by Banbury mixers and roll mills, fabric calendering, bead construction, and tread and sidewall extrusion. Some cooling water and steam derived hot water are used in these operations for temperature control but in comparison with the subsequent molding and curing operation, relatively little steam is used here overall.

The molding and curing operation primarily utilizes steam to shape and vulcanize the green tire. Steam pressures range from 150 to 310 psig with 250 psig as typical overall.[6]. Curing times range from 10 minutes to 24 hours for passenger and earthmover size tires, respectively. Demand for steam by a curing press is either on or off for the curing time period. Since a plant employs several Banbury mixers supplying many curing presses, electrical and steam demand are essentially continous.

Direct fuel use is considered insignificant since it typically represents less than 1% of the total fuel and electricity consumed. It is used in dryers to remove moisture from the tire cord fabric prior to adhesive coating.

4.0 ANTICIPATED TRENDS

This section discusses trends through the year 2000. Major emphasis is on market development and trends in process technology and energy consumption.

4.1 Product Growth Trends

Tire demand has historically been tied to the number of registered automobiles [9] and new car sales. [12] Recently, however, additional factors have emerged, such as:

- increased market penetration of the longer wearing radial tire (wears twice as long as the bias tire thereby decreasing replacement tire demand).
- increased use of mass transit and smaller cars, maintenance of lower speed limits, and the discouragement of car use in urban centers hence, reducing tire wear.
- competition from foreign producers
- the potential of a national fuel rationing plan in the event of a fuel shortage.

As shown in section 2.1, passenger tires represent a major portion of tire production (78% in 1977). Recent trends in the shipments and production show the rebuilding of tire inventory and a recovery from the 1975 recession and 1976 United Rubber Workers strike, thus creating high production levels in 1977. These are expected to taper off in 1978. Illustrated below are tire shipments and production (including the market share of radial tires as a percent of all tire types -bias ply, bias belted, and radial) for 1974 through 1977.

Tire Shipments and Production*

(millions of tires)

Passenger Tires	1974	% Radials[3]	1975	% Radials[4]	1976	% Radials[2]	1977	% Radials
Production	175.2	28%	157.7	38%	156.5	40%	193.4	43%
Shipments								
Original Equipment	43.4	--	39.7	66%	50.0	65%	55.7	66%
Replacements	124.2	--	123.0	29%	123.5	30%	129.3	33%
Exports	7.6	--	5.3	--	4.1	--	4.6	51%
Total	175.2	28%	168.0	38%	177.6	40%	189.6	43%
(Inventory)	(48.1)	(--)	(43.9)	(--)	(29.2)	(--)	(39.6)	(44%)
Truck and Bus Tires								
Production	35.7	--	28.6	--	31.0	--	40.0	--
Shipments								
Original Equipment	11.9	--	8.1	--	10.1	--	10.3	4%
Replacements	21.3	--	19.8	--	22.4	--	25.9	5%
Exports	1.1	--	0.8	--	0.6	--	0.8	7%
Total	34.3	--	28.7	--	33.1	--	37.0	4%
(Inventory)	(7.2)	(--)	(7.1)	(--)	(5.6)	(--)	(7.6)	(8%)

* Source: Rubber Manufacturers Association

Future trends in tire shipments are difficult to predict since the extent to which the above factors will interact is difficult to assess. In addition, technological advances and social or behavioral changes in the future may also alter the consumption of tires dramatically. Tire shipments forecast to 1985 and 2000 were determined by using historical data and applying a linear regression extrapolation (Exhibit 3011-8).

Tire Shipments

(millions of tires)

Historical*	Forecast	
1975	1985	2000
195.7	275.0	372.4

* Source: Rubber Manufacturers Association

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4.2 Process Changes and Implementation of New Technology

Tire manufacturing processes have changed to accomodate improvements in rubber compounding recipes, tire construction (i.e., radial vs. bias tires, new fabrics for plies or belts, etc.), and tire design. However, the basic technology and process steps have remained similar but with some variation in operating conditions and mechanical design. For instance, radial tires require a different compound formulation than bias tires (i.e., more natural rubber) hence, Banbury mixing times are different as well as curing times and product handling. Also, since the fabric construction is different, the ply fabric preparation and tire building operations are different. Overall, although radial tires weigh more, on the average, than bias tires (35 pounds versus 25 pounds, respectively[6]) and the manufacturing processes differ, the energy consumed per unit weight of product is almost the same.

Recent trends in tire manufacture have been towards improving automobile gas mileage by reducing the rolling resistance. This goal is being reached by altering compound formulations and tire design. Goodyear has developed a tire of elliptical cross-section which is expected to deliver 3% to 7% more miles per gallon than present radial tires, a result of the 34% less rolling resistance.[13] Another approach to improving automobile gas mileage is the elimination or weight reduction of the spare tire. A spare tire 30% narrower, 17% smaller in diameter, and 40% lighter in weight has been developed for temporary use.[14] Also, the spare tire may eventually be eliminated by a tire designed to run smoothly when depressurized (long enough to reach a service station).[14]

The development of "cast-tire" technology to near commercialization is expected within the next few years. The process for casting or injecting liquid polymers into a mold from which a complete pneumatic tire would emerge would radically alter tire manufacture. The new technology would not only require much less capital investment than conventional tire plants but would also cut operating costs by one sixth to one eighth. (The minimum economic size of a cast-tire unit is 1,500 tires/day compared with 9,000 to 12,000 tires/day for a conventional plant.) Various design concepts include two-component (or polymer) one piece cast tires and "closed-torus", steel wire wound, injection molded tires. The two component tire consists of a carcass of stiff polymer which is cast first and a second, tread component of softer polymer cast around the carcass. The closed-torus tire is one in which the entire cross-section of the tire is closed all around the circumference of the tire (as opposed to the conventional open-torus tire which is open around the inner diameter, at the bead that seats against the wheel rim). At present, cast auto and truck tires do not meet current performance requirements but cast tires for agricultural and other special purposes are expected to become a commercial reality in Europe, with exports to the U.S., within this decade. (15)

4.3 Trends in Energy Requirements

In an effort to cooperate with government programs for energy conservation, the Rubber Manufacturers Association (RMA) has adopted a voluntary energy conservation goal of 15.5% by 1980 relative to 1972 usage. (16)

Based on this target, it was assumed that such a reduction in unit energy consumption for the tire industry could be achieved by 1985, relative to 1975, and that an additional reduction of 15% in unit energy consumption between 1985 and 2000 is feasible.

The total estimated energy consumption, including a breakdown showing fuel and electric energy consumed, through the year 2000, is presented below.

Estimated Energy Consumption Trends, 1975-1985-2000

Tire Manufacture

x 10^{12} Btu	1975	1985	2000
Total Purchased Fuel and Electricity	61.6	73.2	81.5
Purchased Fuel**	47.1	55.9	62.3
Purchased Electricity*	14.5	17.3	19.2

* At 3413 Btu/kWh

** Assuming an 80% boiler efficiency, purchased fuel consumption represents the following steam consumption for 1975 through 1985 and 2000.

	1975	1985	2000
Steam (pounds x 10^9) @250 psig	31.4	37.3	41.5

Since fuel consumption by type in this industry is not expected to change substantially through the year 2000,(6) the following fuel breakdown, proportionate with the 1975 Census of Manufacturers, is estimated for the years 1985 and 2000.

Estimated Fuel Consumption by Type, 1975-1985-2000

Tire Manufacture

$\times 10^{12}$ Btu	Purchased Fuel*	Coal	Oil	Gas	Other
1975	47.1	10.2	15.4	20.7	0.8
1985	55.9	12.1	18.3	24.6	0.9
2000	62.3	13.5	20.4	27.4	1.0

* Used to raise steam.

5.0 PLANT SPECIFIC DATA

This section provides available data relating to specific plant energy requirements, load profiles, state conditions, and reliability considerations. Several plant factors are summarized in Exhibit 3011-9.

5.1 Load Profiles

Tire manufacturing plants typically operate 24 hours per day, 5 days per week. Although the manufacturing process at the various steps may be a batch operation, many process lines are operating at the same time. For instance, several Banbury mixers may be supplying several fabric calenders and tread extruders which in turn supply many more tire building machines and finally many curing presses. As a result, overall energy use is continuous and for the on-stream period during the week an electrical load factor is estimated as in excess of 85%.(6) Since the manufacturing facility is shutdown for 2 days of the week, there is no electricity consumed for Banbury mixing and other tire manufacturing operations. However, some electricity is required to maintain necessary loads, e.g. lighting and air conditioning. For the 2 day shutdown period the electrical load factor is estimated at 45%.(6) Overall, for the 7 day week, the combination of the production and shutdown periods, the electric load factor is estimated at 70-75%.

Similarly, the thermal-electrical coincidence factor for the 5 day operating period is estimated to vary between 0.90 and 1.0 and for the 2 day shutdown period it is estimated as the same. Overall, on an annual basis the thermal-electrical coincidence factor is also estimated to vary between 0.90 - 1.0.

5.2 Energy Flow, Mass Flow and State Conditions

As noted in Section 3.2, tire manufacture utilizes primarily electricity and steam. Electricity is used for compound preparation (Banbury mixing) and tire component fabrication (tread extrusion, fabric calendering, bead construction, etc.). Steam is predominantly used in the tire curing and shaping operation. Steam is typically used at 250 psig and also at pressures ranging from 150 to 310 psig.[6] By virtue of the mechanical energy (Banbury mixing) and thermal energy (tire curing), heat is built-up or transferred to the rubber which before each next process step, must be cooled for handling. Banbury mixing, for example, heats the rubber to 110-125°C (dump temperature)[10] after which it is cooled and transferred to the next step where it is heated again and afterwards cooled again and so on (i.e., as in tread and sidewall extrusion, fabric calendering, and tire curing).

It is estimated that a tire plant producing an average 15,000 passenger tires per day would have 3-4 Banbury mixers, of varying size, supplying 250-350 curing presses* operating with a 20 minute curing time period.[6]

In addition, raw material is processed with typically less than 3% waste although some plants produce up to 5% waste.**[6] [11] This waste may be proportionate to the raw material content of a typical

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* The above number of curing presses refers to single presses which cure one tire at a time as compared with duplex presses which cure two tires at a time.

** Percent waste is based on net weight of raw materials (i.e., rubber textile material, etc.), excluding packaging waste such as paper, cardboard, and wood.

tire: rubber - 45%, carbon black - 23%, oils and softeners - 11%, chemicals - 9%, tire cord - 7%, other (bead, etc.,) - 4%, and sulfur -1%.[9]

5.3 Reliability Considerations

In tire manufacture each different process step by itself is a batch operation; as a result, in the event of a total power failure (loss of electricity and steam) each process step will be affected differently.

An electrical power outage would stop equipment such as Banbury mixers, roll mills, extruders, calenders, and other electrically driven equipment. A steam loss would affect primarily the tire curing presses plus any equipment which uses steam to make hot water for temperature control.

In the event of a short electrical power outage of less than 10 minutes, little difficulty would be encountered in the startup or resumed operation of the electrical equipment. However, a electrical power outage of more than 10 minutes would create significantly greater problems. Banbury mixers would be frozen or seized by the rubber compound and therefore, have to be dismantled and cleaned. Similarily tread and sidewall extruders would also seize and require a clean-up.[6]

If a steam loss should occur, the entire production of uncured tires remaining in the curing presses would have to be scrapped. In addition, some mold cleaning would also be necessary. (6)

Overall, a total power loss for less than 10 minutes and greater than 10 minutes would result in 1 to 4 hours and 4 to 24 hours of downtime respectively.[6] In either case, all uncured tires that were in the curing presses during the power failure would have to be scrapped.[6]

EXHIBIT 3011-1

Tire Manufacture Flowsheet

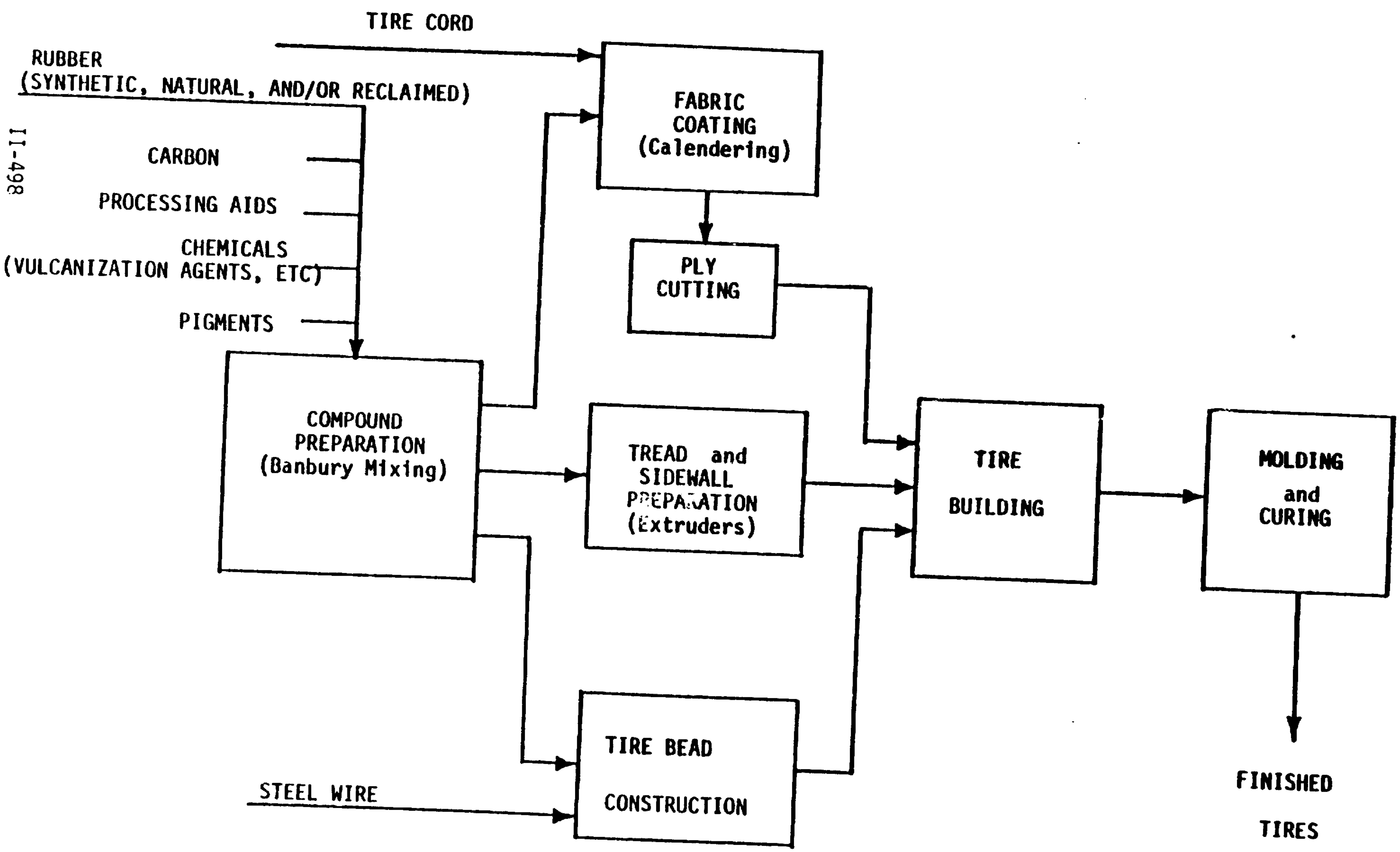
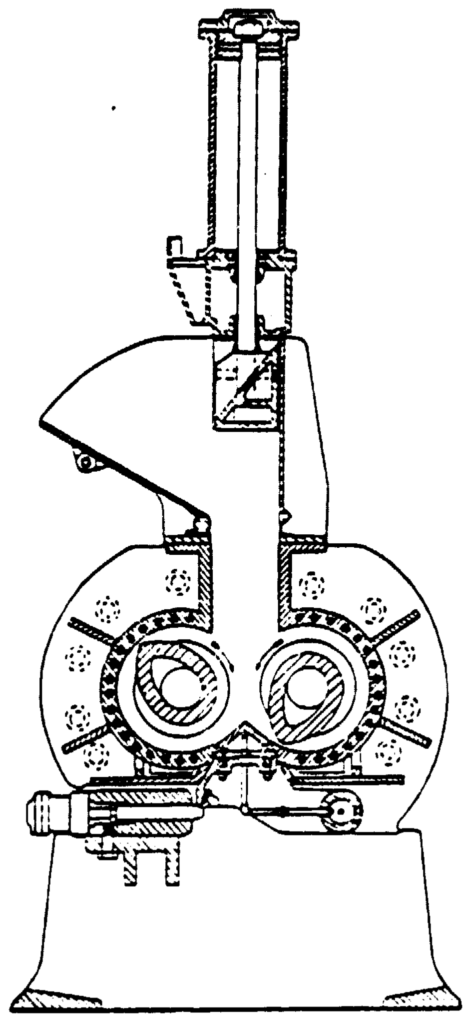


EXHIBIT 3011-2

Banbury Mixer



Source: Perry, R.H. and Chilton, C.H., Chemical Engineers' Handbook, Fifth Edition, McGraw-Hill, New York.

EXHIBIT 3011-3

Tire Cross-Sections

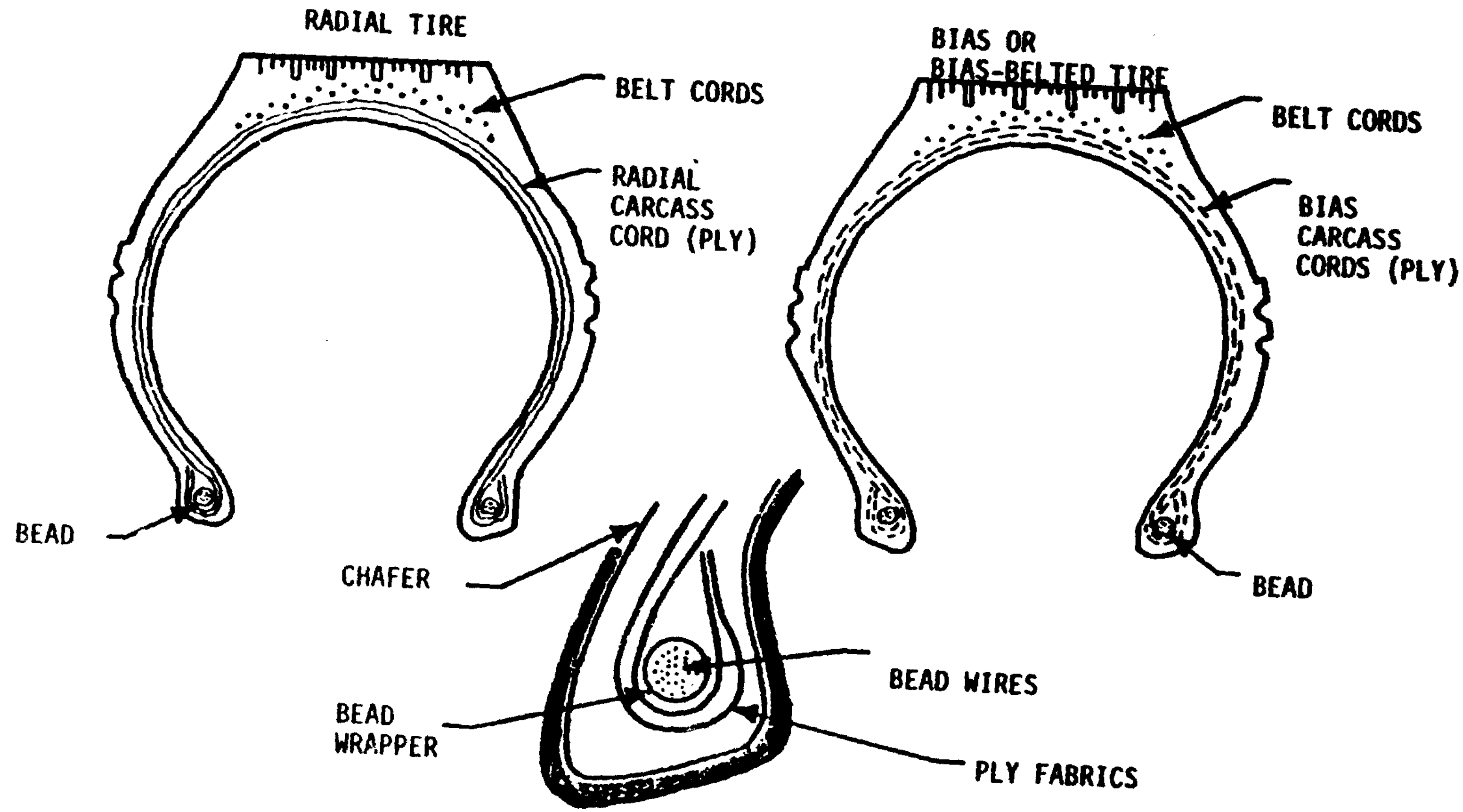
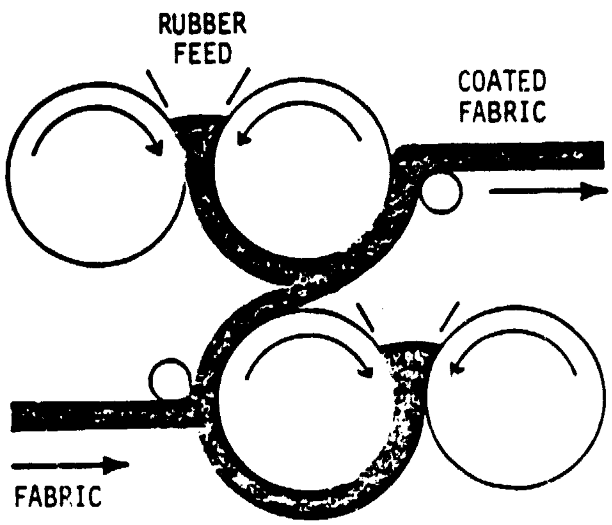


EXHIBIT 3011-4

Fabric Calendering



Source: Kirk-Othmer, Encyclopedia of Chemical Technology, Second Edition, John Wiley and Sons, New York, 1963-1970

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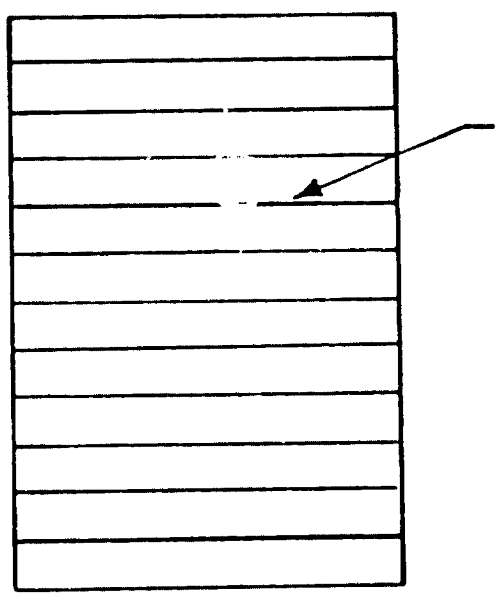
EXHIBIT 3011-5

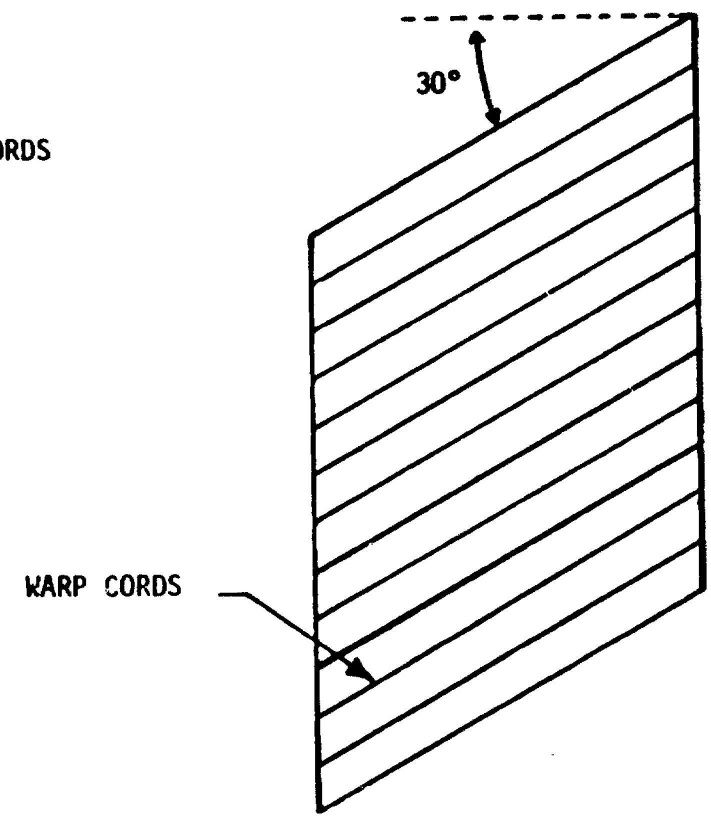
RADIAL TIRE

PLY FABRIC



BIAS TIRE

PLY FABRIC



View: facing tread with tire upright

EXHIBIT 3011-6

ANNUAL NATIONAL DATA (1975), SIC 3011 - TIRES

Product Production Million Tons	Total Energy Consumption Trillion Btu	Purchased** Electricity Trillion Btu	Purchased* Fuels Trillion Btu	Coal*	Oil*	Gas*	Other*	Total Energy Consumption For SIC Trillion Btu	Percent Total*** Energy Consumption Represented
3.91	61.62	14.54	47.08	10.17	15.45	20.68	0.78	76.11	81%

* Purchased fuel consumption was distributed across the various fuel types proportionate with the 1975 Census of Manufactures data for SIC 3011.

** Electricity converted at 3413 Btu/kWh

*** The remaining 19% may be attributed to the manufacture of inner tubes, retreading materials, and other related or ancillary products also classified under SIC 3011.

EXHIBIT 3011-7

Energy Consumption Per Unit Output: Tire Manufacture

Electricity* Million Btu Per Ton	Hot Water Million Btu Per Ton	Steam** (Million Btu Per Ton)			Direct Fuel Million Btu Per Ton	Exhaust Stream	
		To 300° F	300-500°F	Over 500°F		Temperature °F	Energy Million Btu Per Ton
3.72	--	--	9.63	--	***	--	--

* converted at 3413 Btu/kWh

** Derived from total fuel use, assuming an 80% boiler efficiency

*** As discussed in Section 3.2, direct fuel use represents less than 1% of the total fuel and electricity consumed.

EXHIBIT 3011-8

TIRE SHIPMENTS

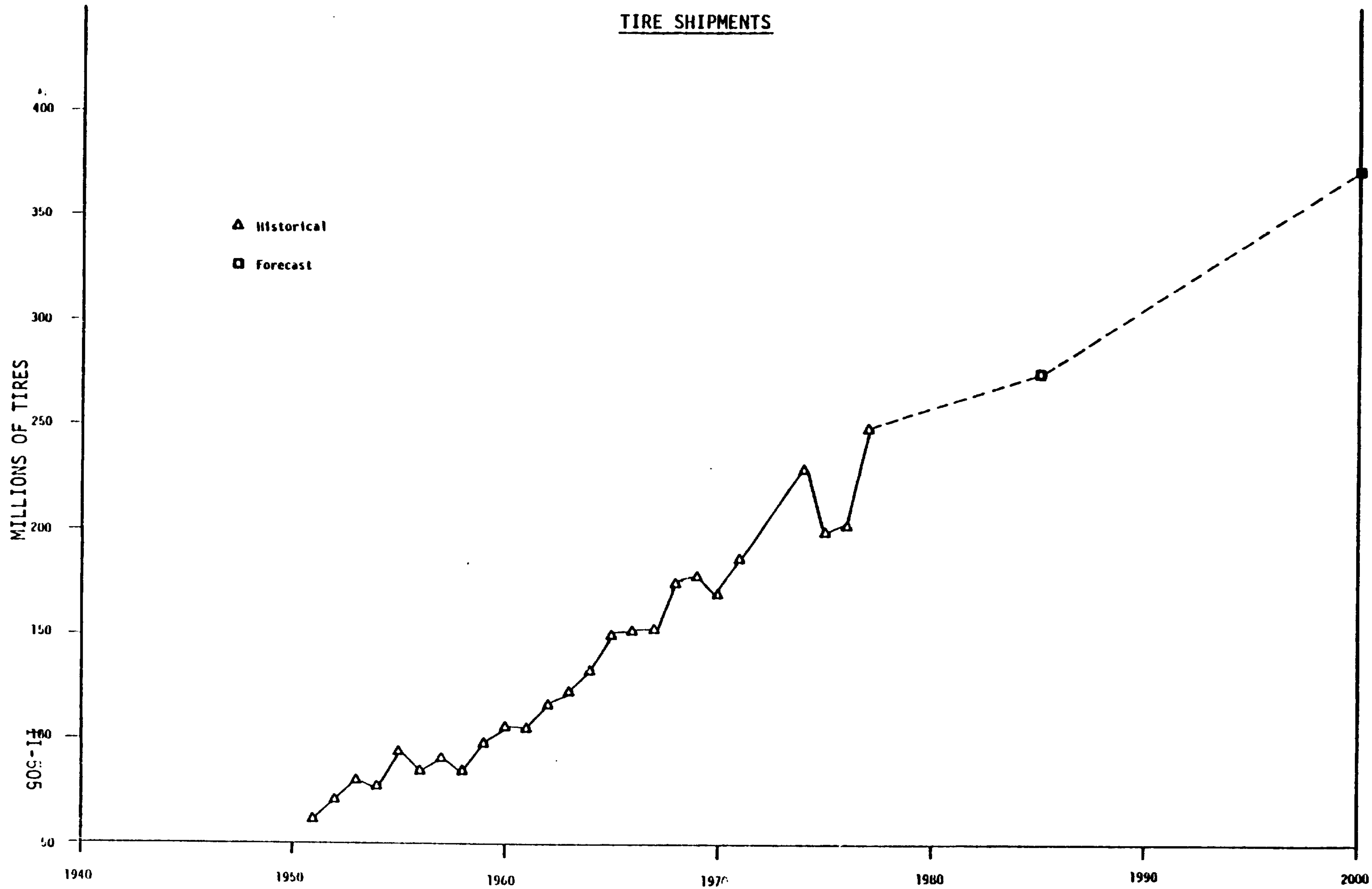


EXHIBIT 3011-9

Tire Manufacturing Plant Factors

Typical Plant Capacity Tons/year	Plant Size Range Tons/year	Electric Load Factor	Thermal Electrical Coincidence Factor	Projected Applicability To 2000
100,000	10,000 to 175,000	70-75%*	0.90-1.0	Good

* Tire manufacturing plants typically operate 5 days/week, 24 hours/day with a 2 day/week shutdown period. During the 5 day production period electric load factors are estimated as in excess of 85% and for the 2 day shutdown period they are estimated at 45%.[6] The above electric load factor (70-75%) is estimated for the 7 day week, the combination of the production and shutdown periods.

Footnotes

(1) Kirk-Othmer, Encyclopedia of Chemical Technology, second edition, John Wiley & Sons, New York, 1963-1970.

(2) Rubber World, February 1978, pp-40.

(3) Rubber Trends, September 1976, pp-9.

(4) Rubber World, February 1977, pp-44.

(5) Rubber World, January 1976, pp-24.

(6) Private communication with industry representatives.

(7) U.S. Department of Commerce, Bureau of Census, "Annual Survey of Manufactures, Fuels and Electric Energy Consumed", 1975.

(8) Rubber Trends, September 1977, pp-62.

(9) Dworkin, David, "Tires", Chemical Week, McGraw-Hill, New York, May 19, 1971, pp-37.

(10) Morton, M., Rubber Technology, second edition, Van Nostrand Reinhold, New York, 1973.

(11) U.S. Environmental Protection Agency, "Rubber Reuse and Solid Waste Management", 1971.

(12) Rubber World, January 1977, pp-40.

(13) Rubber World, September 1977, pp-21.

(14) "Chementator, General Motors Opts for New Compact Spare Tires in its Mid-Size 1978 Models", Chemical Engineering, McGraw-Hill, New York, September 12, 1977, pp-88,89.

(15) "Cast-Tire Technology Gets Ready to Roll", Chemical Engineering, McGraw-Hill, New York, May 22, 1978, pp-51-53.

(16) Rubber World, June 1977, pp-8.

STEEL PRODUCTION

1.0 PROCESS IDENTIFICATION

This section identifies and specifically defines the industry, and provides a brief description of the current production processes employed.

1.1 SIC Classification

The production of steel is classified under SIC code 3312, which covers "establishments primarily engaged in manufacturing hot metal, pig iron, silvery pig iron, and ferroalloys from iron ore and iron and steel scrap; converting pig iron, scrap iron and scrap steel into steel; and in hot rolling iron and steel into basic shapes such as plates, sheets, strips, rods, bars and tubing."

1.2 Process Description

The production of basic steel shapes involves three major sequential steps:

1) Smelting iron ore into pig iron
2) Refining pig iron and scrap into steel
3) Forming basic steel shapes from raw steel.

Together with these major steps are ancillary operations such as the production of coke from metallurgical coking coal, and the production of sinter from iron ore concentrates. A block flow diagram of the major processing stages is shown in Exhibit 3312-1. The paragraphs which follow provide a brief description of the current process technology employed in each of major process steps.

Coke Production

One of the most important ancillary operations associated with smelting is the production of coke. Almost all the coalbased coke in the U.S. is produced by the "byproduct" (or retort) method. The by-product coke oven is a long narrow chamber lined with refractory brick: coke plants consist of a number of ovens, each of which operates intermittently in rotation to produce a continuous supply of coke oven gas. Crushed coal is fed into the oven which is then sealed. The exterior of the oven is then heated by combustion of previously produced coke oven gas (when coke oven gas alone is used as fuel about 40% of the gas produced is burned to heat the ovens).[1] The coal starts to fuse at the walls, which are at about 2000°F. Coking proceeds gradually towards the center of the coal charge, while volatile products are removed in the vapor phase for subsequent recovery. The coking finishes about 17 hours later, at which time doors at the end of the oven are opened and a ram pushes the hot coke into a quenching car. The car takes the coke to a quenching station where it is sprayed with water. The coke is finally allowed to cool and is screened before being fed into the blast furnace.

Sinter Production

Sintering is an agglomeration process used to prepare blast furnace raw materials so they are permeable to gas flow and are not excessively blown out of the blast furnace into the gas recovery system.

1 United States Steel, "The Making, Shaping and Treating of Steel," ninth edition, 1971, chapter 4.

Sintering is carried out on a moving grate which conveys a bed of finely divided iron bearing materials mixed with (approximately 5%) coke breeze or finely divided anthracite.[1] The bed is ignited at the feed end of the grate by gas burners. Down draft combustion pulls air down through the bed burning the fuel mix therein at about 2500°F (at the feed point).

Smelting iron ore and sinter into pig iron

Iron ore and sinter are reduced to metallic iron in blast furnaces. The blast furnace consists of a vertical vessel about 100 feet high, lined with refractory brick (see Exhibit 3312-2). Iron ore, sinter, coke and fluxes[2] are charged into the top in alternate layers and move slowly down. Blasts of hot air, frequently enriched with oxygen, are injected into the bottom of the furnace through holes, or "tuyeres." The oxygen in the air reacts with the coke to produce carbon monoxide. Temperatures rise to over 3000°F in the combustion zone. The hot gases from this zone travel up the furnace and heat the descending "burden".

The smelting process occurs in several stages. The ore, coke and flux are preheated at the top of the blast furnance by the hot exit gases. As the charge descends, a partial reduction begins to occur at temperatures around 1200°F. The carbon monoxide in the gases reacts with the iron ore to produce carbon dioxide and lower oxides of iron. For example, hematite ore reacts as follows:

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1 United States Steel "The Making, Shaping and Treating of Steel," ninth edition, 1971, Chapter 5.

2 Fluxes are materials such as calcium carbonates and magnesium carbonate which supply oxygen, when they thermally decompose, for the reduction of iron ores.

$Fe_3O_4 + CO \rightarrow 3FeO + CO_2$

While the iron ore is reacting, the flux materials are starting to become calcined:

$CaCO_3 \rightarrow CaO + CO_2$

$MgCO_3 \rightarrow CO_2$

As the burden continues to descend, the temperature rises to around 2000°F, when direct reduction occurs. In this reaction, the incandescent coke and iron oxides react to produce metallic iron and carbon monoxide gas.

The final reactions occur in the hearth of the furnace where temperatures finally rise to about 3000°F. Oxides of manganest, silicon and phosphorus react with solid coke as follows:

$MnO + C \rightarrow Mn + CO$

$SiO_2 + 2C \rightarrow 2CO$

$P_2O_5 + 5C \rightarrow 2P + 5\ CO$

Oxide or iron is also reduced:

$FeO + CO \rightarrow Fe + CO_2$

Most of the sulfur in the ore is removed in the slag:

$FeS + Cao + C \rightarrow CaS + Fe + CO$

At the hearth, the iron and slag become molten and are subsequently removed periodically by "tapping" the furnace. The pig iron produced from the blast furnace requires further processing to make steel.

Refining of Pig Iron and Scrap into Steel

The pig iron leaving the blast furnace may contain up to 4.5% carbon and lesser quantities of silicon, manganese, phosphorous and sulfur. To produce steel, all these elements have to be removed to a greater or lesser extent, carbon content dropping to 0.4% for a typical high carbon steel and to 0.2% for a typical low carbon steel.[1] Alloy steels contain small quantities of elements such as nickel, chromium and molybdenum, which improve mechanical and corrosion resistance properties. Stainless steels contain significant quantities of nickel or chromium, sometimes both, and small amounts of other metals.

Three generic types of steel furnaces are used in the U.S. today. These are the open hearth furnace, the basic oxygen furnace and the electric furnace.

The open hearth furnace is a long shallow bath which is heated by a flame above the metal which flows in the hearth of the furnace. The fuel for the furnace may be natural gas, coke oven gas, fuel oil, tars or combinations of these. Fuel and combustion air are introduced alternately from each end of the furnace, the combustion products passing out the opposite end through chambers of brick checker work which are then used to preheat the incoming fuel and air on the next cycle. The furnace charge consists of pig iron, scrap and flux. Often molten pig iron is available from adjacent blast furnaces and therefore this is charged directly to the furnace, thereby minimizing the energy (and time) required to heat the charge. In the open hearth furnace, as in all steelmaking furnaces, the objective is to heat the charge to a final temperature of 2950°F.

1. Skinner, W. and Rogers, D.C.D, "Manufacturing Policy in the Steel Industry," 3rd edition, 1970, p. 99.

The energy supply to the open hearth furnace comes almost entirely from the fuel, i.e. the process is not dependent on thermal energy derived from the oxidation of elements dissolved in the metal. This means that there are no significant limitations on charge composition. In 1973, the average charge to open hearth furnaces contained about 45% scrap, which has the advantage of supplying some of the required oxygen from attached rust and scale.[1] In practice, it is necessary to keep heating time to a reasonable figure for economic reasons, thus the scrap is limited to around 70%, since pig iron contains the carbon to supply agitation to the melt through the evolution of carbon monoxide.[2] In 1974 the open hearth process accounted for 24% of all U.S. raw steel production.[3]

The use of the basic oxygen furnace has been increasing steadily over the past few years. In 1974 56% of all raw steel is the U.S. was produced using this process.[3]

The basic oxygen furnace consists of a cylindrical, refractory lined vessel which can be rotated on a horizontal axis towards one side for charging and the other side for pouring. Molten pig iron and scrap are charged to the furnace and oxygen is blown at the surface through a lance. Slag forming fluxes, such as lime, are added. Scrap contributes some oxygen to the process in the form of rust and scale. Unlike the

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1. Battelle Columbus Laboratories," Potential for Energy Savings in the Steel Industry", prepared for the FEA, January, 1975.

2. Bodsworth, C. and Bell, H.B., "Physical Chemistry of Iron and Steel Manufacture", Longman Publishing Co., London, 1972, p. 242.

3. American Iron and Steel Institute, "Annual Statistical Report, 1975", 1976, p. 53.

open hearth and electric furnaces, the basic oxygen furnace requires no supplementary source of heat. The thermal energy comes from sensible heat in the molten charge and the heat subsequently generated by the oxidation of carbon and other impurities. Preheating the scrap allows a greater percentage to be added; normally the maximum amount of scrap added is about 30% of the total charge.[1]

Heating time for the basic oxygen process ranges from about 45 minutes to 1 hour. Control of the process by means of composition analyses is therefore difficult in so short a cycle, and control of the charge composition becomes important.

The use of the electric furnace has been increasing in recent years, mostly at the expense of the open hearth furnace. In 1974, the electric furnace accounted for about 20% of all U.S. raw steel production.[2]

There are two types of electric furnace, the electric arc and the electric induction furnace. The electric arc furnace consists of a refractory-lined cylindrical steel shell which can be tilted to pour off molten metal and slag. Graphite electrodes are extended through the roof of the furnace towards the charge. An electric arc is established between the electrodes across the metal and is maintained until the charge is melted and the required degree of refining is achieved.

The electric induction furnace consists of a refractory crucible inside a copper conduction coil. Induced currents are set up in the metal charge, causing it to melt. After a pool of molten metal is formed, the induced current causes the metal to swirl against the solid metal, increasing the rate of melting. Since a significant

1. Battelle Columbus Laboratories, Potential for Energy Savings in the Steel Industry", prepared for FEA, Jan. 1975, p. iv-3.

2. American Iron and Steel Institute, "Annual Statistical Report 1975", 1976, p. 53.

level of slag cannot be maintained in this process, it is used only for remelting and homogenizing a charge of the desired composition and not for refining.

The electric furnace has an advantage over the open hearth and basic oxygen furnaces in making alloy steels. Conditions can be controlled in the electric furnace to prevent excessive oxidation of alloying metals and their subsequent removal in the slag.

Charge to electric arc furnaces is almost always scrap; in 1974, for example, the average charge to electric furnaces in the U.S. contained about 97% scrap.[1] Heating time in electric furnaces varies with furnace size, type, age and temperature of charge. Typically the heating time may range from 2 to 3½ hours.

Semi-finishing of Steel

Molten steel from the steel furnaces is either poured into ingots and milled into slabs, billets and blooms or is continuously cast and cut into shape.

Continuous casting of steel into semi-finished shapes has been practiced to a limited extent in the U.S. since the 1940's. Because continuous casting methods do not involve the production of ingots and their subsequent reheating prior to forming, continuous casting is less energy intensive than the conventional process (see below). Three process designs for continuous casters are illustrated in Exhibit 3312-3.

The traditional route to semi-finished steel products involves the pouring of the liquid steel from a ladle into molds to form ingots. These ingots are reheated (to a uniform temperature) of 2150°F - 2450°F in soaking pit furnaces.[2] These soaking pit furnaces are generally

1. American Iron and Steel Institute, "Annual Statistical Report 1975," 1976, p. 72.

2. United States Steel, "The Making, Shaping and Treating of Steel," Pittsburgh, 1971, p. 661.

fueled with coke oven gas and blast furnace gas. The purpose of the soaking pit furnace is to soften the ingots so that they may be rolled. The heated ingots are then rolled to form the semi-finished products. These may include slabs, blooms and billets.

Rolling Mills and Finishing Lines

Semi-finished shapes (slabs, blooms, billets) are heated in reheat furnaces so that they can be hot rolled to the desired shape and size. Reheat furnaces may be fired with fuel oil, coke-oven gas, or natural gas. Less than 1% of the national steel reheating capacity uses electric induction heating.[1] It is not possible to describe in detail in this report all the processing steps which are utilized to manufacture the various basic steel products used in the U.S. These steps may include: hot rolling, cold rolling, heat treating, galvanizing, tinplating, cleaning, pickling, drawing and welding.

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1 Battelle Columbus Laboratories, "Potential for Energy Savings in the Steel Industry", prepared for FEA, January 1976, p. iv-15.

2.0 NATIONAL DATA

The annual national data presented in this section are summarized in Exhibit 3312-4. The derivation and significance of the production and energy consumption data are discussed in the following sub-sections.

2.1 Capacity and Production Data

Total U.S. production of raw steel was 128 million tons in 1976 of which 23.5 million (18%) tons was produced in open hearth furnaces, 79.9 million tons (62%) in basic oxygen furnaces and 24.6 million tons (20%) in electric furnaces. Production in 1976 was equivalent to 80.9% of raw steel capacity which was 158 million tons.[1]

Shipments of steel products in 1976 was 89 million tons (net of shipments between steel companies).[2] Exhibit 3312-5 shows the shipments of steel products for 1976 by product type.

There were 245 companies classified under SIC 3312 in 1972. Of these companies the four largest accounted for 45% of the total value of shipments for the SIC code. The 50 largest accounted for some 96% of the total value of shipments for the SIC.[3]

Plants classified under SIC 3312 may either be fully integrated facilities or may be smaller cold metal shops. Integrated facilities usually use iron ore, sinter and pellets together with scrap as their source of iron feed. Integrated facilities usually will contain one or more blast furnace, one or more (in any combination) open hearth, basic oxygen and electric arc steel furnaces, and various semi-finishing and finishing operations. A cold metal plant, on the other hand, uses

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1. American Iron and Steel Institute, "Annual Statistical Report 1976", 1977, p. 53.
2. Ibid, p. 28.
3. U.S. Bureau of the Census, Department of Commerce, "The Statistical Abstract of the U.S.," October 1977, p. 808.

primarily scrap materials and purchased pig iron in electric steel furnaces. These facilities (often called mini-mills) do not have blast furnaces, but do include one or more types of semi-finishing and finishing operations. Of 182 steel producing companies in the U.S. in 1974, 168 (or 92%) each produced less than 1% of the national total steel production and can be classified as mini-mills.

An example of a very large integrated steel complex is the Indiana Harbour Works of the Inland Steel Company. It is reported that this facility has 579 coke ovens, 8 blast furnaces, 19 open hearth steel furnaces, 4 basic oxygen furnaces, 2 electric furnaces, billet and slab continuous casting, soaking pits, heating furnaces, and hot and cold rolling mills.[1] An example of a mini-mill is the American Compressed Steel Corp. of Cincinatti. It is reported that this facility has one electric arc furnace (capacity 6 tons/heat), one heating furnace and one bar mill. It produces steel ingots and reinforcing bars. The annual rolling capacity of this plant is 12,000 tons/year.[2] The hot rolling capacity of Inland Steel is reported to be nearly 17 million tons/year. Thus the output of facilities in this industry may vary by as much as three orders of magnitude.

2.2 Annual Energy Consumption

Energy consumption data for SIC 3312 reported in the "Annual Survey of Manufactures", reflect only purchased fuels and electricity. The steel industry uses a very large quantity of fuel (particularly coal) from captive sources. Therefore the national data on energy consumption was taken from surveys conducted by the American Iron and Steel Instutute.

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1. American Iron and Steel Institute, "Directory of Iron and Steel Works of the United States and Canada", Washington, D.C., 1974, p. 146-55.

2. Ibid., p. 12-13.

The following table gives the consumption of primary energy sources for the steel industry:

ENERGY CONSUMPTION: THE STEEL INDUSTRY

Energy Source	Unit	1976 Consumption	1975 Consumption	1974 Consumption
Coking Coal	Ton	76.068×10^6	75.515×10^6	81.567×10^6
Steam Coal	Ton	3.044×10^6	3.101×10^6	3.959×10^6
Purcnased Coke	Ton	7.743×10^6	4.257×10^6	7.046×10^6
Fuel Oil	Bbl	38.425×10^6	34.505×10^6	42.276×10^6
Liquid Petroleum Gas	Bbl	0.627×10^6	0.740×10^6	0.276×10^6
Natural Gas	BCF	595.383	576.939	670.396
Electric Power (Purchased)	kWh	54.302×10^9	50.661×10^9	56.743×10^9

SOURCE: American Iron and Steel Institute, "Annual Statistical Report 1976," Washington, D.C. 1977, p. 67-74.

Note: Above does not include steam, self-generated electric energy, self produced coke, coke oven gas or blast furnace gas as these are generated from the above listed primary energy sources.

3.0 PROCESS ENERGY REQUIREMENTS

The sub-sections which follow describe in depth the energy consumed per unit of production in the iron and steel industry, as well as providing detail on the type of energy required. A summary of the energy requirements per unit of output appears in Exhibit 3312-6.

3.1 Unit Energy Consumption Data

The manufacture of semi-finished steel products, and the raw steel to produce them is a very energy intensive process. Coal, natural gas, fuel oil and electric energy supply the majority of the purchased fuel and energy requirements. Coke, coke oven gas, pitch and tars, steam and blast furnace gas produced onsite from purchased materials are all used to supply energy to the various process steps.

For the purpose of this report a unit of production is defined as one ton of typical semi-finished product mix and the raw steel required to manufacture that ton of semi-finished product.

The composition of the typical ton of semi-finished product mix was determined by choosing the top 8 volume products shipped in 1974[1], and normalizing their composition to 100% (they accounted for 87% of shipments in 1974). The products and their share of the product mix are shown below:

Item	%
Galvanized sheets	6.9
Tin Plate	6.9
Structurals and Rails	9.2
Tubes and Pipes	10.3
Plates	11.6
Hot Rolled Sheets	16.1
Cold Rolled Sheets	19.5
Bars	19.5
	100.0

1. Based on AISI Statistics for 1974.

The processing sequence assumed for this report is indicated in Exhibit 3312-7. Continuous casting is assumed to account for 10% of bloom. billet and slab production. The steel furnace portion of the process reflects the national average split for the year 1974; that is 24.36% by open hearth furnace, 55.96% by basic oxygen furnace, and 19.67% by electric furnace.

As will be demonstrated in Section 5.2 of this report, 1.207 tons of raw steel are needed to manufacture 1 ton of the product mix outlined above. Total purchased fuels per ton of product mix are shown below:

Energy Type	10^6Btu/Ton Product Mix
Coking Coal	17.697
Purchased Coke	0.728
Steam Coal	0.094
Natural Gas	3.292
Fuel Oil	0.900

In addition to the purchased fuels, 1.116 x 10^6 Btu of electric energy (converted at 3413 Btu/kWh) are required. Coke, coke oven gas, and blast furnace gas produced onsite are also consumed to supply process energy requirements.

Some plants have recently used small quantities of liquid petroleum gas to meet a portion of their fuel requirement. This practice generally arose out of necessity during a natural gas curtailment situations.

Coke oven gas, produced as a by-product of coke production, is very important fuel in integrated steel mills. It is used to underfire coke ovens, fire blast furnaces, and heat open hearth steel furnaces, as well as to supply energy to semi-finishing operations. The energy content of coke oven gas is approximately 500 Btu/cubic foot, half the heating value of natural gas.

Blast furnace gas, produced as a by-product of blast furnace operation is utilized to supply some of the steel mill's energy requirements. The energy content per unit volume of blast furnace gas is rather low (approximately 95 Btu/cubic foot), consequently it is often necessary to enrich this gas with natural gas to achieve combustion. Recovery of this energy stream is often as low as 70%. Nearly one third of the blast furnace gas is consumed in blast furnace operations. The remaining portion of the gas is used to raise steam, self-generate electricity, and to a smaller extent (when enriched) to supply energy to downstream operations.

3.2 Details of Electricity Consumption

Electrical energy is utilized in virtually every portion of an integrated steel mill, e.g. for materials handling (conveyors, cranes, stackers, chargers and transfer cars/ladles), cooling water circulation, process use (such as electric steel furnaces, electric heating furnaces), and other plant auxiliary uses. Exhibit 3312-8 presents data on electrical energy requirements in each stage of an integrated steel mill. The requirements are expressed in terms of 10^3 Btu/ton of product mix.

The plant configuration is the same as described previously in Section 3.1. This exhibit shows the largest electric energy consumers in the raw steel section of the plant to be the electric furnace and blast furnace. Mini-mills or small steel mills using primarily scrap would use considerably larger quantitities of electric energy per unit of production. The data in Exhibit 3312-8 implicity assume the national average mix of steel making furnaces (electric furnace is only 19.67%).

Another consumer of electrical energy in some steel mills is the production of oxygen. In 1974 an average of 1.83 thousand cubic feet of oxygen were required per ton of raw steel produced. The industry, however, produced only 11.5% of the oxygen it used in 1974.[1] For this reason oxygen production is not considered in this report. Oxygen manufacture is electric energy intensive, requiring approximately 450 kWh/ton produced.

Electric steel mills are generally operated continuously (some product lines may be idled in times of slack demand). There is some time required between heats to charge and discharge steel furnaces. Electric furnaces (in facilities having more than a single furnace) are alternatively operated so as to maintain as high an electric load factor as is practical (utility bills increase as customer load factor decreases). Load factors for integrated steel mills range from 0.65 to 0.80. Modern, fully integrated facilities will have electric load factors close to 0.80.[2]

Steel mills tend to rely on purchased electrical power to meet their electric energy requirements. Self generated power supplied 19% of industry requirements in 1974 (18% in 1976) according to AISI statistics.

3.3 Details of Thermal Energy Consumption

The production of raw steel, and semi-finished steel products is extremely thermal energy intensive. The largest portion of the energy is supplied by coke (which is mostly produced onsite from bituminous coal).

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1. American Iron and Steel Institute, "Annual Statistical Report 1976," 1977, p. 74, 53.

2. Based on personal communications with an official of an integrated steel company.

The blast furnace, which is the most energy intensive process step consumes 12.6×10^6 Btu of coke per ton of product mix ultimately produced.

Steam is used to supply a portion of the energy requirements in several process areas. Exhibit 3312-9 presents data on steam use in the integrated steel mill described in previous sections. Total steam use is approximately 1.4×10^6 Btu/ton of product mix. Naturally the choice of a different product mix or processing sequence would result in a different steam consumption value. Most steam used in the steel industry is generated at between 300 and 500^o F. Waste heat boilers and blast furnace gas - (sometimes enriched with natural gas) fired boilers are the most popular methods of raising steam. Occasionally, steam production may be in excess of requirements in which case the excess is vented. However, this does not occur continuously, and the system cannot be characterized quantitatively.

As was mentioned in section 3.2, a portion of the electrical energy demand in some steel mills is met by onsite generation. It is usual for plants generating electricity to use the steam cogenerated to satisfy a portion of the process requirements.

An energy balance for the hypothetical integrated steel mill discussed in this report is presented in Section 5.2.

4.0 ANTICIPATED TRENDS

This section discusses the trends which are likely to occur in the industry through the year 2000. The major emphasis is on three areas: production, process technology and energy consumption.

4.1 Product Growth Trends

In 1977, over 125 million tons of raw steel were produced. Shipments of steel products in 1977 exceeded 91 million tons.[1] Steel products are used in a multitude of applications, including: construction, consumer durables, transportation and national defense.

There are many factors which have an impact on the health of the steel industry. In the past, the steel industry has been rather sensitive to a general economic downturn. For example, in 1975 production of raw steel fell 29 million tons from the previous year. It is not possible to fully discuss all the factors likely to influence the future well being of the U.S. steel industry in this report, however some of the key issues are mentioned below.

- Penetration into traditional end uses for steel by other products will continue to have a negative influence on steel production (for example: aluminum in automobile parts and beverage containers, plastics in construction materials and automobile parts).

- Environmental problems faced by the industry will be expensive to remedy.

- Growth in production will be adversely affected by foreign imports (often at lower prices).

- Capital availability and cost will be a problem in financing new plants and improving existing facilities.

- Steel production is very energy intensive, therefore the rising cost of energy will impact particularly hard on the steel industry.

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1. American Iron and Steel Institute, "Annual Statistical Report 1977," May 1978.

There are several ways in which the likely level of future steel production can be forecast. Three different methods were used for the purpose of this study. The first method uses a linear extrapolation (least square fit) of production statistics for the period 1956-1977. The second method assumes that the average ratio of steel production to GNP (constant 1972 dollars, for the period 1956-1977) will remain constant and that the GNP will grow at 2.3% (in constant 1972 dollars) per annum. The final method assumes the production of steel per capita (average for 1956-1977) will remain constant and that the U.S. population will grow at the rate forecast by the census bureau (average of high and low estimate).[1] The results are presented in tabular form below:

FORECAST PRODUCTION OF RAW STEEL
(10^6 tons)

Year	Method I (Linear Function)	Method II (GNP Method)	Method III (Population Model)
1985	155.1	216.0	145.0
1990	164.4	244.3	152.2
2000	183.0	312.8	163.9

The results of methods I and III, as well as historical trends are illustrated in Exhibit 3312-10; the Method II prediction seems to be inconsistent with historical trends and with the results of the other methods. An independent forecast by Predicasts Inc. indicates 1990 production to be 190 metric tons (209.38 short tons),[2] which seems high in comparison with the Method I and III prediction but serves to illustrate the volatility and uncertainty associated with this industry's future.

1. U.S. Bureau of the Census, "Statistical Abstract of the U.S.," October 1977, p. 6.

2. Predicasts Inc. "Special Study #142", Cleveland, Ohio, May 27, 1977.

4.2 Process Changes

The production of raw steel and semi-finished steel products involves a large number of process steps, as has been discussed in Sections 2 and 3 of this report. Thus, there are a very large number of possible process changes being studied for possible implementation in the steel industry. Four of the more promising alternative process techniques are outlined in the following paragraphs.

Dry Coke Quenching

The current U.S. practice in metallurgical coke production involves wet quenching of the incandescent coke after removal from the coking oven. Dry quenching of coke involves the use of an inert gas as the cooling agent, with subsequent heat recovery from the gas in steam. The use of a major portion of the coke's sensible heat via this process can yield 900-1000 pounds of high pressure steam per ton of coke quenched. This technology has been demonstrated in the Soviet Union, but has not seen commercial use in the U.S. because of the high associated capital cost and the large amount of existing coking capacity.

Direct Reduction of Iron Ore

Direct reduction represents an alternative to the conventional blast furnace for reduction of iron ore to iron. The two processes differ in several respects, including fuels utilized (reformed natural gas or non-coking coals for direct reduction; metallurgical coke for blast furnaces) and product delivered (solid sponge iron from direct reduction; molten iron from the blast furnace). Because the iron produced by direct reduction still contains the gangue present in the ore, the major use of the product is in electric steelmaking furnaces, although

the product can be used in almost any steelmaking process that uses scrap (e.g. basic oxygen furnaces). At this time, it would be difficult to estimate the energy savings possible by use of direct reduction of iron ore in place of blast furnace operations.

Continuous Casting

Continuous casting is a process by which liquid steel is transformed into blooms, billets or slabs directly from the steel furnace; a number of intermediate steps which are necessary for the older, conventional cooling processes are thereby eliminated. In addition, steel yields from continuous casting are higher than those from conventional processes. Energy savings of about 1.5 million Btu per ton of cast product are realized by utilization of continuous casting machines instead of conventional steel rolling processes. The continuous casting capacity which exists at present can process only about 10-15% of the steel industry's current output of raw steel. New continuous casting equipment is very expensive and the industry is pessimistic about additional cost allocations because it must be justified in terms of additional realizable sales of finished products made from this route.

Induction Furnaces

Reheating of steel slabs, blooms and billets is performed in gas fired reheat furnaces. As natural gas supplies have been subject to curtailment, steel manufacturers have become more interested in the use of electric energy, and particularly induction heating, for this purpose. The process is environmentally acceptable since the heating unit releases no flue gases. Induction heating is particularly suitable for continuous casting equipment because of its instantaneous response to automatic control and its ability to put heat exactly where needed.

Induction furnace heating would add considerably to the process electricity needs of a steel mill, while displacing some fuel gas requirements. For slabs alone 96 kWh of electricity/ton of slabs would be needed, to replace 2.78 million Btu of energy in the form of natural gas, fuel oil and coke oven gas.

A study recently released by the U.S. Department of Energy identified the most promising areas for research and demonstration of energy saving technologies in the iron and steel industry. The most promising areas according to that study are: improved reheating furnaces, improvements to the blast furnace (including the injection of coal), development of a clean fuel gas generator fueled with coal, increased use of scrap, and increasing yields in steelmaking.[1]

The percentage of production represented by the three types of steel making furnaces has varied substantially in recent years. Exhibit 3312-11 shows the percentage of raw steel production by type of furnace, for the period 1965-1977. Open hearth furnace production has fallen off sharply during this period, while basic oxygen furnace production has risen sharply. Electric furnace production has risen steadily during this period. It is expected that these general trends will continue in the period between now and the year 2000.

4.3 Implementation of New Technology

The iron and steel industry is a capital intensive one and is therefore slow to make technological changes. Additionally, raw steel production in the U.S. in 1977 was only 78.4 percent of industry capacity,[2]

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1 A.D. Little Inc., "Research, Development and Demonstration for Energy Conservation - Preliminary Identification of Opportunities in Iron & Steelmaking," prepared for the U.S. Department of Energy, Jan. 1978.

2 American Iron and Steel Institute, Annual Statistical Report 1977, May 1978, page 53.

so that new facilities are unlikely to be construed, and major technological changes are unlikely to be widely implemented until existing capacity is more fully utilized.

It is expected that electric steelmaking furnace capacity will continue to increase steadily as it has in the past. This will allow increased use of scrap and consequently less energy for mining, coking and blast furnace operations.

Technological improvements such as dry coke quenching will not, in our opinion, be implemented to any great extent prior to 1985. If fossil fuel prices escalate in cost faster than electric energy, induction heating will become more attractive to the steel industry. Decreased availability of natural gas will further influence steel industry planning.

4.4 Trends in Energy Requirements

In setting the energy efficiency improvement "target" for SIC 33 subcomponent data for SIC 3312 was presented. A component "target", which can be estimated from the "target" document for SIC 33, is a 14.7% reduction in unit energy consumption by 1980 relative to 1972 energy consumption levels. This includes factors considered to be both technologically feasible and economically practicable. The build-up of the "target" is illustrated from Exhibit 3312-12, taken from the "target" document for SIC 33.[1]

If the assumption is made that the economically practicable and technologically feasible conservation measures will be implemented by 1985 and that all technologically feasible measures shown can be implemented by 2000, the energy consumption estimates for these years can be estimated.

1. Battelle Columbus Laboratories, "Development and Establishment of Energy Efficiency Improvement Targets for Primary Metal Industries; SIC 33", Prepared for FEA, August 13, 1976.

The straight line product growth predictions of Section 4.1 were used in preparing the future energy consumption predictions, which are presented in Exhibit 3312-13.

It is not expected that the fuel mix used in 1985 and 2000 will vary greatly from the mix of fuels used in 1975. The 1975 fuel mix was:

Coal	69%
Natural Gas	19%
Fuel Oil	7%
Other	5%
	100%

5.0 PLANT-SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements, including indications of load profiles, mass flows, and reliability considerations. Several plant factors are summarized in Exhibit 3312-14.

5.1 Load Profiles

Electric power load factors in the steel industry generally range from 0.65 for older facilities to 0.80 for modern plants. Ideally integrated steel mills are operated continuously, although some product lines may be idled in times of slack demand. Some non-productive time is required between steel furnace heats for charging and discharging, however companies operating multiple electric furnaces tend to operate them alternatively so as to maintain as high a load factor as is practical.

Fully integrated, modern steel mills will have load factors around 0.80.[1] Newly built, or renovated plants will probably not have load factors exceeding 0.80.

5.2 Energy and Mass Flows

In order to establish unit energy flows for a steel mill producing the product mix described in Section 3.1 of this report, it is necessary to work backwards from the final product to the raw steel accounting for the yield in each process step. Exhibit 3312-15 traces the flow of products through the various semi-finishing and finishing operations. It was determined that 1.207 tons of raw steel are required to produce 1 ton of product mix. The yields for the various semi-finishing and finishing

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1. Based on personal communications with an official of a company operating integrated mills.

operations are those reported in a recent study by Battelle.[1]

An energy and material flow diagram for the raw steel section of the integrated steel mill is shown in Exhibit 3312-16. This diagram is from a report prepared recently by Gordian Associates for the North Atlantic Treaty Organization. The basis of the exhibit is the production of one metric ton of raw steel, average U.S. practice in 1974. Material flows are in terms of metric tons per metric ton of crude steel, and energy flows are in terms of 10^9 Joules per metric ton of crude steel. (Note: 10^9 Joules/metric ton is equivalent to 1.16×10^6 Btu/short ton.) In order to produce one ton of product mix, 1.207 tons of raw steel are required. Therefore 1.095 metric tons of liquid steel is needed for downstream processing. The energy flows given in the exhibit are used in this report by converting 10^9 Joules to Btu and multiplying by 1.095, with the three following exceptions. Firstly, the energy associated with oxygen production is not included. Secondly, the only electrical usage shown in the exhibit is for the electric furnace (no steam usage is shown). Finally blast furnace gas is assumed 100% recovered in the exhibit, while it is considered to be 70% recovered in this report.

Exhibit 3312-17 shows the energy flows for the semi-finishing operations (all operations after crude steel production). Steam usage is not shown in this exhibit, however steam use can be obtained by reference to Exhibit 3312-9. Total energy consumption in semi-finishing operations is shown below:

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1. Battelle Columbus Laboratories, "Potential for Energy Savings in the Steel Industry," prepared for FEA, January 1975, Appendix A.

Energy Type	Quantity (10^6 Btu/ton of Product Mix)
Electricity	0.733
Steam	0.133
Natural Gas	2.709
Fuel Oil	0.021
Coke Oven Gas	0.759
Total	6.355

The energy requirements of downstream operation may now be compared to the energy available (in the form of coke oven gas and blast furnace gas) from the raw steel portion of the process. After satisfying the downstream demand for coke oven gas with the coke oven gas available from the raw steel section (supplemented with 0.401 x 10^6 Btu/unit of blast furnace gas), it is found that 1.049 x 10^6 Btu/unit of blast furnace gas is available. This quantity of gas could be used for electric power generation and/or steam raising. If electrical generation is 33% efficient, and the available blast furnace gas is used to maximize electric power generation, 31% of the electrical power requirements could be met by self generation using the blast furnace gas. Alternatively, the gas may be used to generate steam or to cogenerate steam and electricity in varying proportions.

5.3 Reliability Considerations

It is important for a steel mill to have a reliable source of electric power. While it is unlikely that severe damage will result in the raw steel section of the plant as the result of a momentary power interruption, the results of an interruption of several hours could be very severe. If molten material were to solidify in an electric steel furnace, or blast furnace, it is possible that the refractory linings of these vessels would be ruined. Additionally, production losses involved would be considerable.

Materials being rolled in semi-finishing operations would have to be removed from the rolling equipment before the mill could be re-started, so as to avoid the possibility of damaging the drives. Materials undergoing processing at the time of a power interruption would most likely be recycled as scrap.

Voltage control of electric drives for rolling mill equipment is of considerable importance. The drawing process for the production of flat rolled products, sheet and strip, and for other forms (wire, for example) requires a high degree of control so as to insure accurate dimensioning of the final product. Industry personnel contacted were quick to indicate the critical nature of voltage control, although the degree of control necessary to insure product quality was generally not known.

EXHIBIT 3312-1

PRODUCTION OF STEEL PRODUCTS

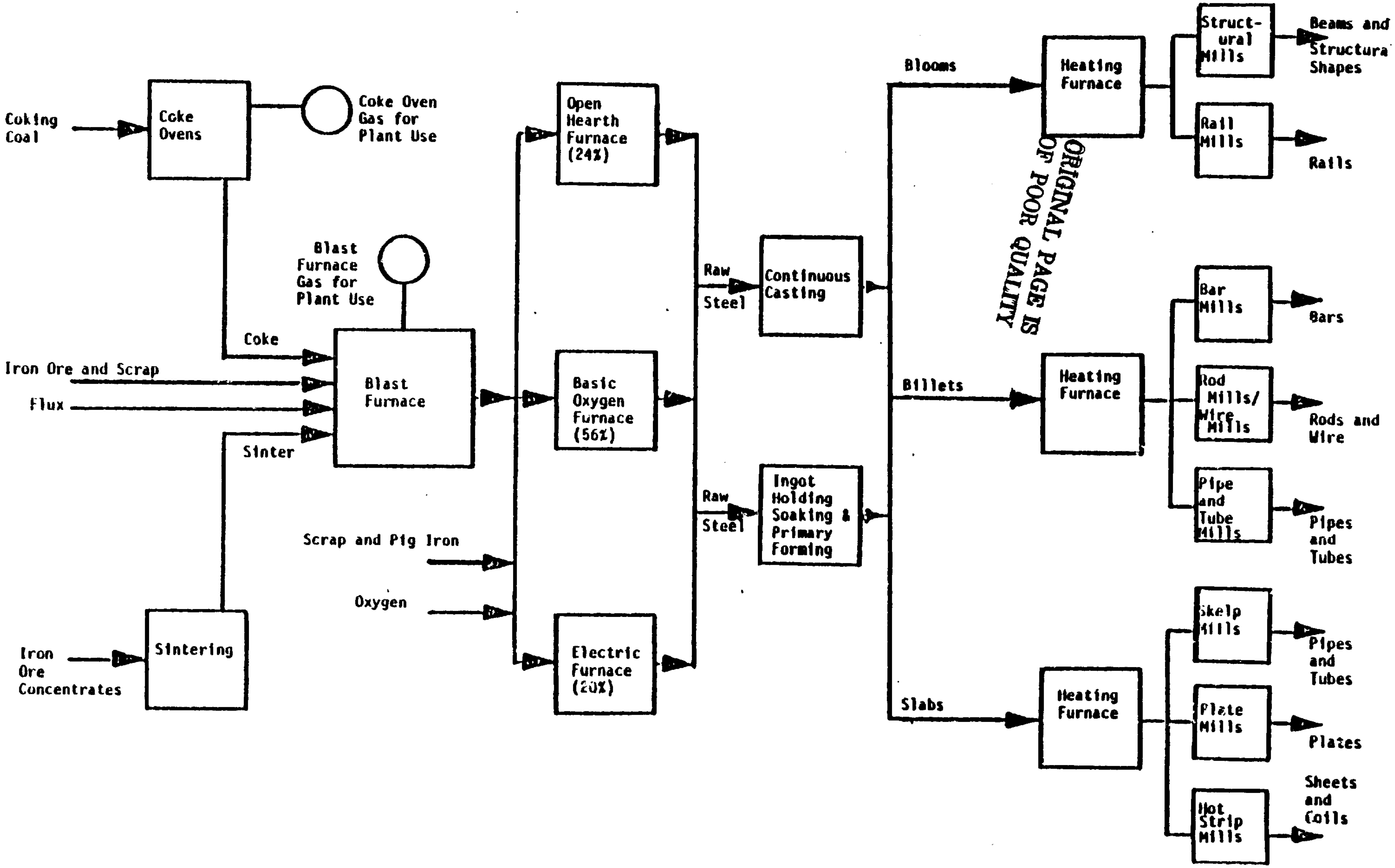
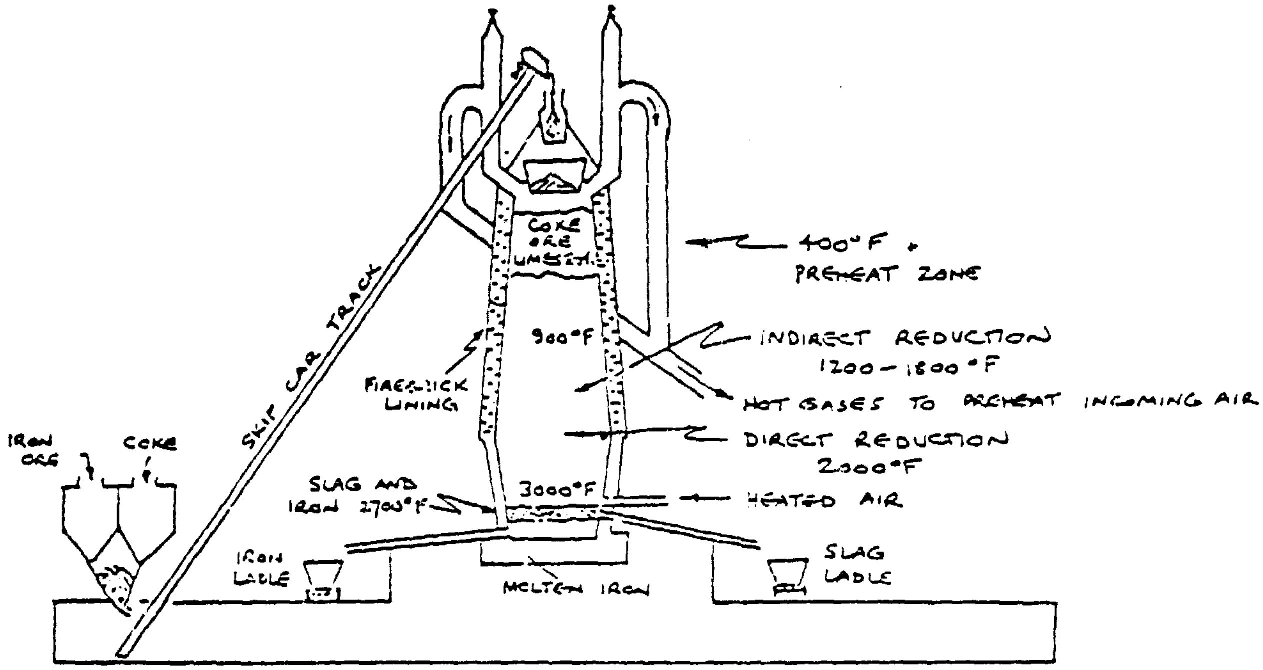


EXHIBIT 3312-2

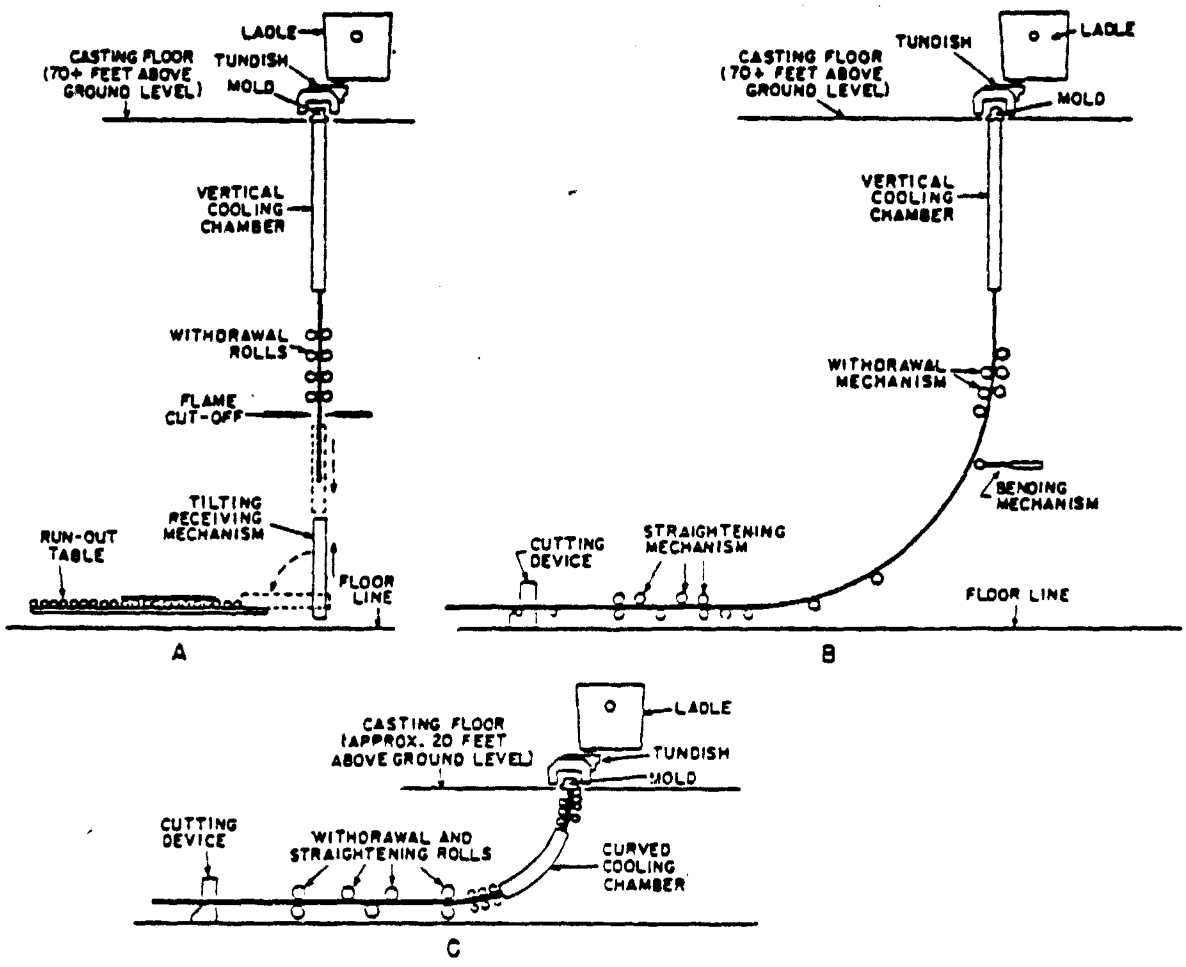
BLAST FURNACE DIAGRAM



Source: Gordian Associates Inc. "The Data Base, the Potential for Conservation in Nine Selected Industries", June 1974. Prepared for the Federal Energy Administration, Section 9.0.

EXHIBIT 3312-3

THREE DESIGNS OF CONTINUOUS CASTING MACHINES



Source: United States Steel "The Making, Shaping and Treating of Steel," Ninth Edition, 1971, Pittsburgh, p. 708.

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EXHIBIT 3312-4

ANNUAL NATIONAL DATA, THE STEEL INDUSTRY

Year	Production Million Tons Raw Steel	Total Energy* Consumption Trillion Btu	Purchased* Electricity Trillion Btu	Purchased Fuels Trillion Btu	Coal	Oil	Gas	Other**
1976	128.0	3,335.2	185.3	3,149.9	2,056.9	233.2	595.4	246.4
1975	116.6	3,140.4	172.9	2,967.5	2,044.1	209.4	576.9	137.1
1974	145.7	3,567.3	193.7	3,373.6	2,223.7	256.6	670.4	222.9

* Purchased electricity converted at 3413 Btu/kWh

** Includes LPG and purchased coke.

EXHIBIT 3312-5

1976 SHIPMENTS OF STEEL PRODUCTS IN THE U.S.
(tons)

Steel Products	Total Net Shipments	Percent of Total Net Shipments
Ingots and steel castings	487,807	0.6
Blooms, slabs, billets, sheet bars	1,967,356	2.2
Skelp	27,685	
Wire Rods	1,900,618	2.1
Total Semi-Finished	4,383,466	4.9
Structural shapes (heavy)	3,857,402	4.3
Steel Piling	329,913	0.4
Plates	7,159,825	8.0
Total Shapes and Plates	11,347,140	12.7
Rails - Standard (over 60 lbs.)	1,302,961	1.5
- All other	37,216	
Joint bars	18,658	
Tie plates	250,504	0.3
Track spikes	104,640	0.1
Wheels (rolled and forged)	174,995	0.2
Axles	128,580	0.2
Total Rails and Accessories	2,017,554	2.3
Bars - Hot Rolled	7,822,146	8.8
- Bar-Size light shapes	841,966	0.9
- Reinforcing	3,875,717	4.3
- Cold finished	1,618,087	1.8
Tool steel	76,321	0.1
Total Bars and Tool Steel	14,234,237	15.9
Pipe and tubing - Standard	1,781,960	2.0
- Oil country goods	1,678,373	1.9
- Line	1,019,374	1.1
- Mechanical	1,259,891	1.4
- Pressure	196,893	0.2
- Structural	298,169	0.3
- Stainless	30,698	0.1
Total Pipe and Tubing	6,265,358	7.0
Wire - Drawn	1,920,762	2.1
- Nails and staples	280,560	0.3
- Barbed and twisted	70,532	0.1
- Woven wire fence	134,146	0.1
- Bale ties and baling wire	53,682	0.1
Total Wire and Wire Products	2,459,682	2.7

EXHIBIT 3312-5 (cont.)

1976 SHIPMENTS OF STEEL PRODUCTS IN THE U.S.
(tons)

Steel Products	Total Net Shipments	Percent of Total Net Shipments
Black plate	614,145	0.7
Tin plate - Electrolytic and Hot dipped	4,783,683	5.3
Tin Free steel	966,648	1.1
Tin Mill products - all other	71,521	0.1
Total Tin Mill Products	6,435,997	7.2
Sheets - Hot rolled	15,089,543	16.9
- Cold rolled	18,264,751	20.4
Sheets & strip - Galvanized - Hot dipped	4,914,531	5.5
- Electrolytic	265,329	0.3
- All other metallic coated	843,950	0.9
- Electrical	576,574	0.7
Strip - Hot rolled	1,195,991	1.3
- Cold rolled	1,152,478	1.3
Total Sheets and Strip	42,303,147	47.3
TOTAL SHIPMENTS	89,446,581	100.0

Source: American Iron and Steel Institute, "Annual Statistical Report 1976", 1977, p. 28.

EXHIBIT 3312-6

ENERGY CONSUMPTION PER UNIT[2] OUTPUT IN THE STEEL INDUSTRY

Electricity[1] Million Btu Per Unit	Hot Water Million Btu Per Unit	Steam[4] (Million Btu/Unit) To 300°F	Steam[4] (Million Btu/Unit) 300-500°F	Steam[4] (Million Btu/Unit) Over 500°F	Direct Fuel Million Btu Per Unit	Exhaust Stream[5] Temperature °F	Exhaust Stream[5] Energy Million Btu Per Unit
1.1155	-	-	1.4244	-	22.711[3]	-	-

---

1. Converted at 3413 Btu/kWh

2. 1 unit is 1 ton of semi-finished products and the raw steel needed to manufacture that ton of semi-finished products (see Section 3.1 for an explanation).

3. Total direct fuel required is as follows:

   Fuel oil 0.900 x 10^6 Btu/unit
   Natural Gas 3.292 x 10^6 Btu/unit
   Steam Coal 0.094 x 10^6 Btu/unit
   Coking Coal 17.697 x 10^6 Btu/unit
   Purchased Coke 0.728 x 10^6 Btu/unit

   In addition, coke, coke oven gas and recovered blast furnace gas produced on-site from purchased fuels are used as fuel.

4. Steam is generally generated in this temperature range. Some producers raise steam as hot as 700°F using blast furnace gas as fuel.

5. Steam in the steel industry is most often raised in waste heat boilers or by firing blast furnace gas. When steam production exceeds demand, steam is vented.

EXHIBIT 3312-7

PROCESS FLOW SCHEMATIC FOR AN INTEGRATED STEEL PLANT

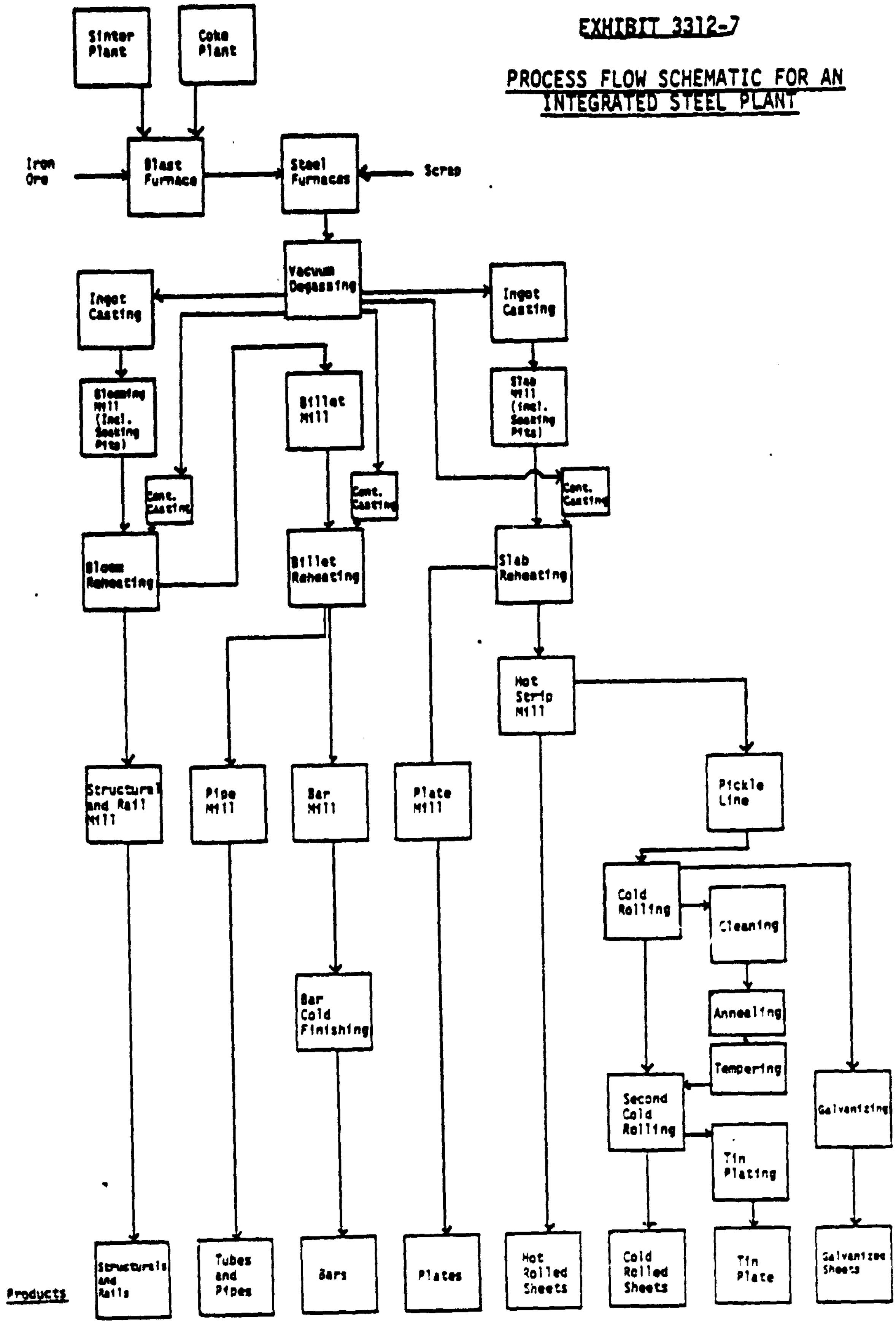


EXHIBIT 3312-8

ELECTRICAL ENERGY REQUIREMENTS IN STEEL PRODUCTION

Area	10^3 Btu/Ton Product Mix[1]
Sinter Plant	34.6
Coke Plant	39.0
Blast Furnace	103.0
Open Hearth Furnace	15.1
Basic Oxygen Furnace	69.2
Electric Furnace	121.3
Pipe and Tube Mill	33.1
Bar Mill	37.2
Bar Cold Finishing	13.9
Structural/Rail Mill	13.8
Billet Mill	47.3
Billet Reheat Furnace	3.4
Galvanizing Line	11.8
Tin Line	25.3
2nd Cold Rolling Mill	35.7
Temper Mill	8.8
Annealing	8.0
Cleaning Line	2.4
Cold Rolling	96.1
Pickle Line	15.9
Hot Strip Mill	194.9
Plate Mill	44.5
Slab Reheat Furnace	5.8
Bloom Reheat Furnace	4.1
Continuous Cast Billets	1.7
Continuous Cast Bloom	3.4
Continuous Cast Slabs	4.9
Vacuum Degassing	8.2
Slabbing Mill	62.0
Blooming Mill	43.8
Ingot Casting	7.2
Total	1115.4

1. Electrical Energy Converted at 3413 Btu/kWh

Sources: Derived from the following sources based on product mix detailed in Section 3.2 of this Report:

1) NATO, Committee on the Challenges of Modern Society, "Industrial International Data Base - The Steel Industry", prepared by Gordian Associates, 1977.

2) Battelle Columbus Laboratories "Potential for Energy Savings in the Steel Industry", prepared for FEA, January, 1975.

EXHIBIT 3312-9
STEAM USE IN STEEL MILLS

Process Area	10^3 Btu/Ton of Product Mix
Coke Plant	338.0
Blast Furnace	953.0
Billet Reheat Furnace	1.2
Cleaning Line	23.4
Pickle Line	48.4
Vacuum Degassing	60.4
Total	1424.4

Source: Derived from the following source based on the product mix in Section 3.2, and the yield pattern presented in Section 5.3 of this Report:

Battelle Columbus Laboratories, "Potential for Energy Savings in the Steel Industry", prepared for the FEA, January 1975.

EXHIBIT 3312-10

HISTORIC AND FUTURE PRODUCTION OF RAW STEEL IN THE U.S.

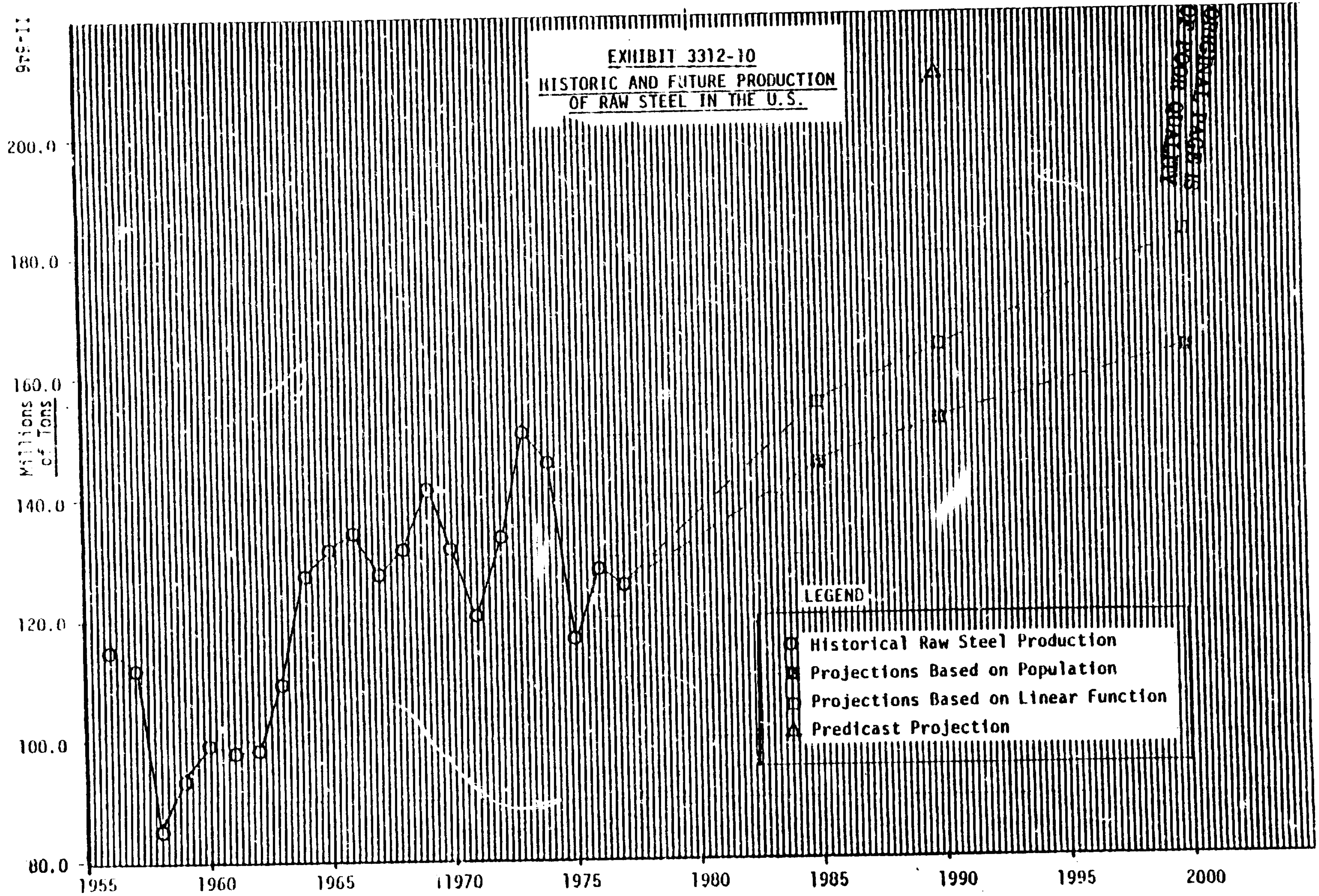
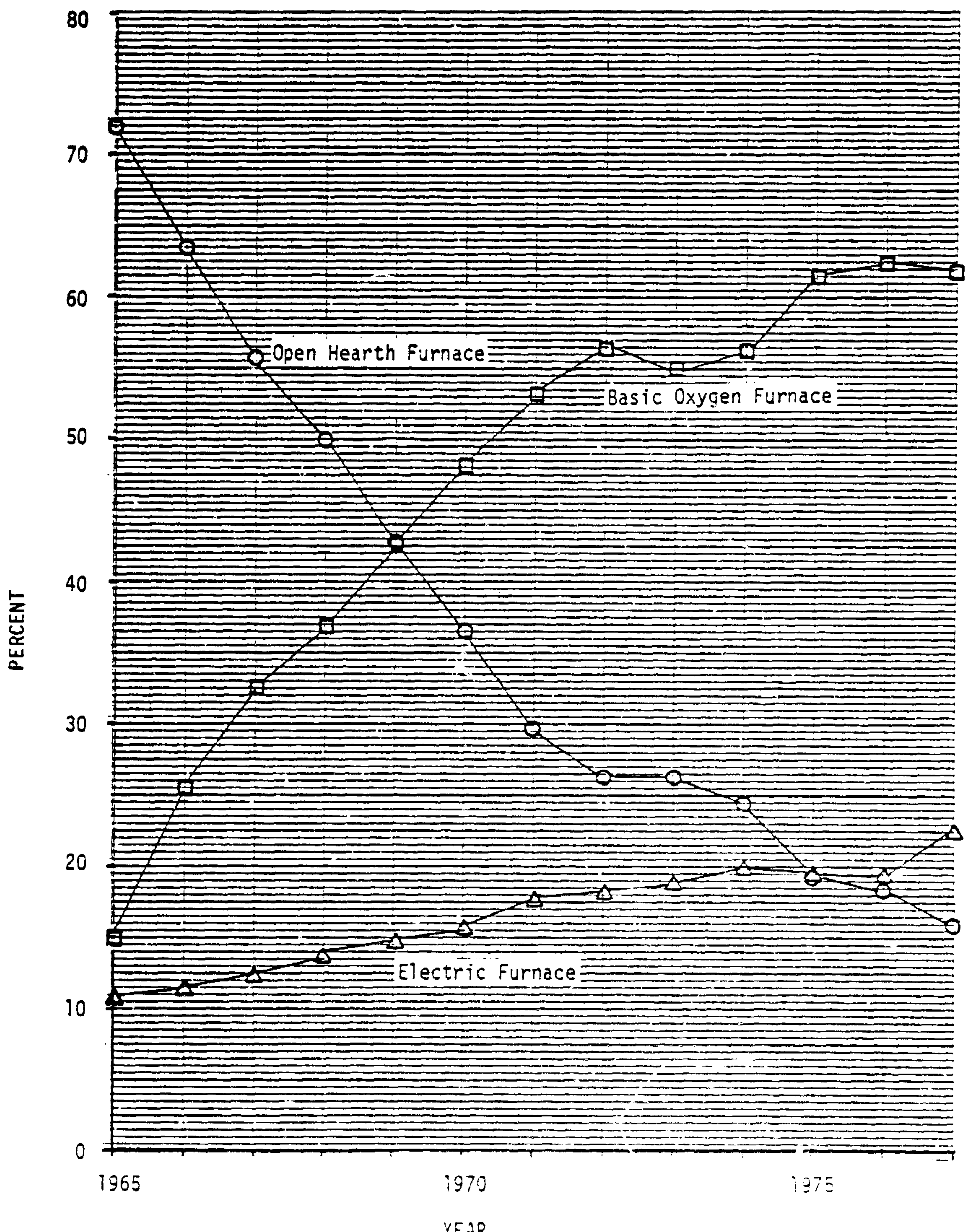


EXHIBIT 3312-11

PERCENT OF TOTAL RAW STEEL PRODUCTION
BY TYPE OF FURNACE



Source: AISI Data

EXHIBIT 3312-12

ENERGY EFFICIENCY IMPROVEMENT POTENTIAL BY 1980; STEEL PLANT SUBCOMPONENT (SIC 3312)

Technique	Potential Saving, 10^6 Btu Per Ton of Finished Steel[(a)] Technologically Feasible	Technologically Feasible and Economically Practicable
Increased pellet usage in blast furnace	+1.09	+1.09
Increase in coke ash	-0.49	-0.49
Increase in coke sulfur	-0.04	-0.04
Increase blast-furnace gas recovery	+0.39	+0.39
New and modernized blast furnaces	+0.13	+0.13
Dry quenching of coke	+0.14	0.0
Blast-furnace coal injection	+0.09	0.0
External desulfurization	+0.16	+0.16
Substitution of basic-oxygen furnaces for open-hearth furnaces	-0.07	-0.07
Recovery of BOF offgas	+0.04	0.0
Preheating scrap for BOF with oxygen-fuel burner	+0.12	0.0
Increased electric-furnace capacity	+2.01	+1.56
Increased continuous casting	+0.73	+0.57
Increased use of induction heating of steel slabs	+0.24	+0.08
Improvements in soaking pit, reheat, annealing, and heat-treating facilities	+0.68	+0.45
Housekeeping	+0.65	+0.65
Total	5.9 (b)	4.4 (b)

(a) + indicates a saving, - indicates more energy required
(b) Rounded totals

Source: Battelle Columbus Laboratories, "Development and Establishment of Energy Efficiency Improvement Targets for Primary Metal Industries; SIC 33", prepared for the FEA, August 13, 1976, p. III-2.

EXHIBIT 3312-13

ESTIMATED ANNUAL ENERGY CONSUMPTION IN STEEL PRODUCTION FOR SELECTED YEARS

(All Data in Btu x 10^{12})

	1975(1) (Base Year)	1985(3)	2000(4)
Purchased Fuel	2,967.5	3,367.0	3,739.9
Purchased Electricity(2)	172.9	196.2	217.9

(1) From Exhibit 3312-4.

(2) Electricity converted at 3413 Btu/kWh

(3) Data for 1985 based on following assumptions

(a) Unit energy consumption 14.7% lower than in 1975

(b) Total raw steel production is 155.1 x 10^6 tons, as per section 4.1 of this report.

(4) Data for 2000 based on following assumptions

(a) Unit energy consumption 19.7% lower than in 1975

(b) Total raw steel production is 183.0 x 10^6 tons, as per section 4.1 of this report.

EXHIBIT 3312-14

STEEL MILL PLANT FACTORS

Typical Plant Capacity (Tons/Year)	Plant Size[1] Range (Tons/Year)	Electric Load Factor	Thermal Electrical Coincidence Factor	Projected Applicability To 2000
5,000,000	1,000,000-10,000,000[2]	0.80	1.0	Good

1. Mini-mills, which do not have blast furnaces, produce less than 500,000 tons per year.
2. U.S. Department of Interior, Bureau of Mines, "Mineral Facts and Problems", 1975 edition, p. 567.

EXHIBIT 3312-15
MATERIAL FLOWS IN THE FINISHING SECTION OF AN INTEGRATED STEEL MILL

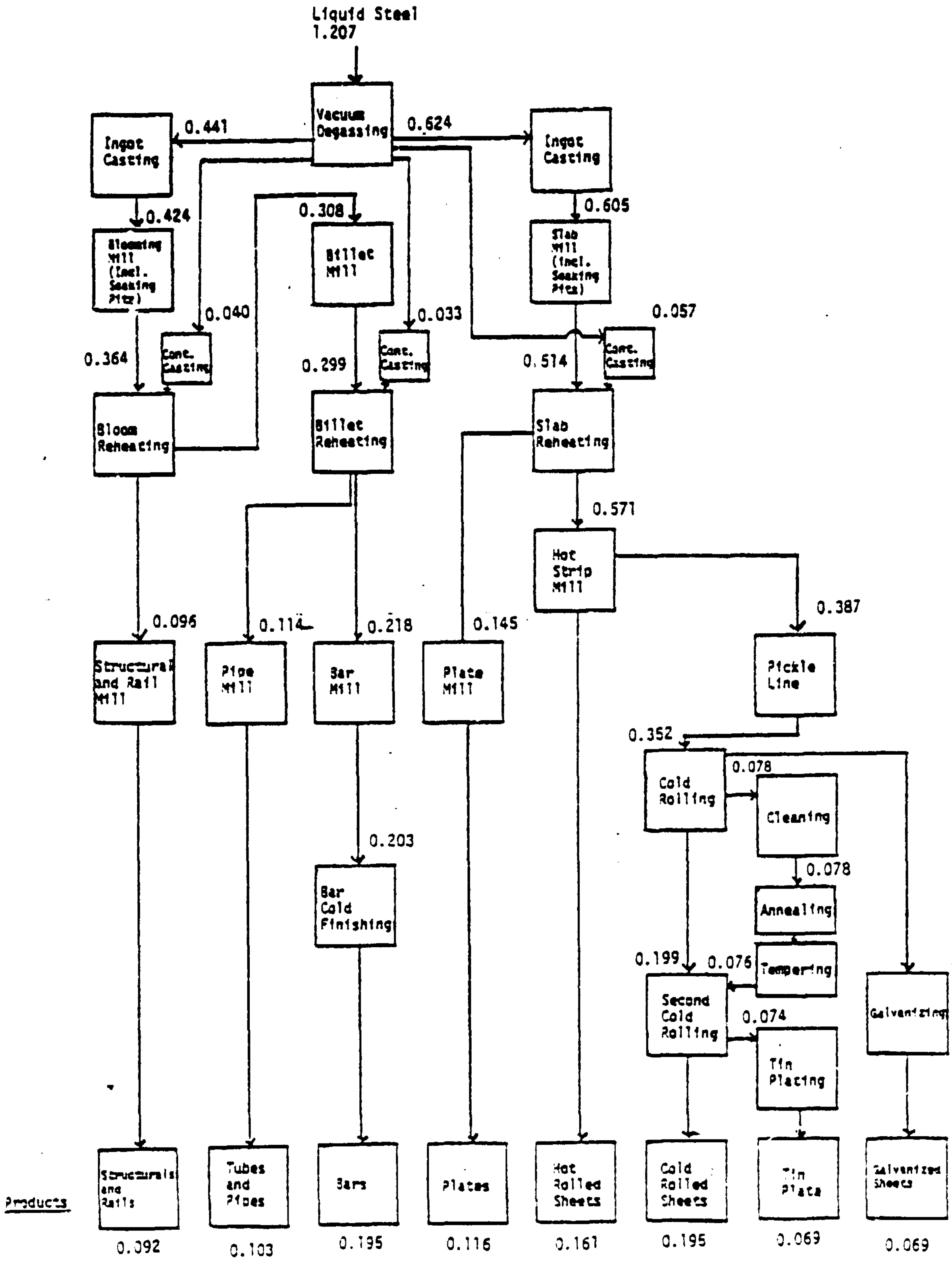
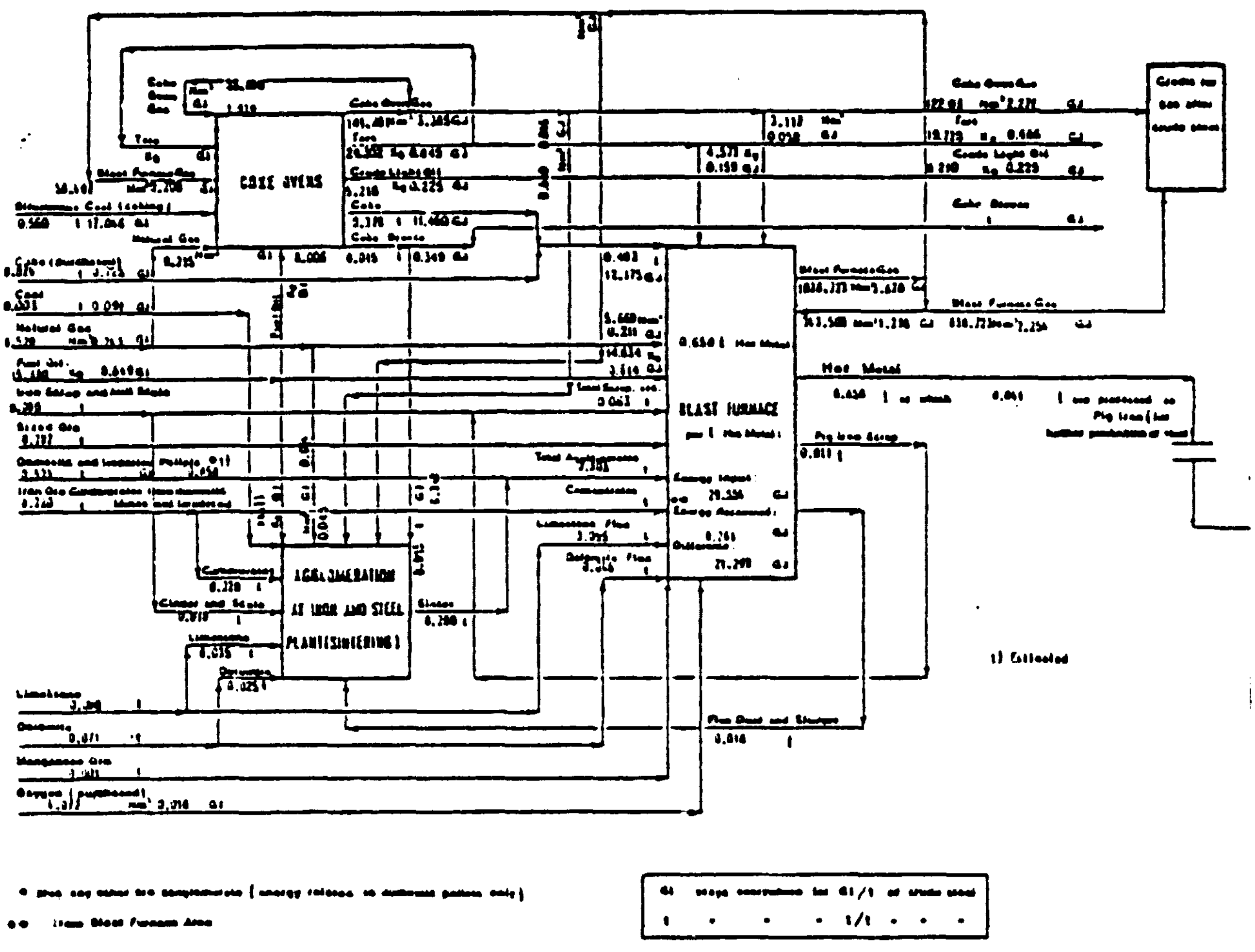


EXHIBIT 3312-16

MATERIALS AND ENERGY CONSUMPTION FOR THE BLAST FURNACE AND CRUDE STEEL PRODUCTION AREAS:

ONE METRIC TON OF CRUDE STEEL

(page 1)



(Exhibit continues on following page)

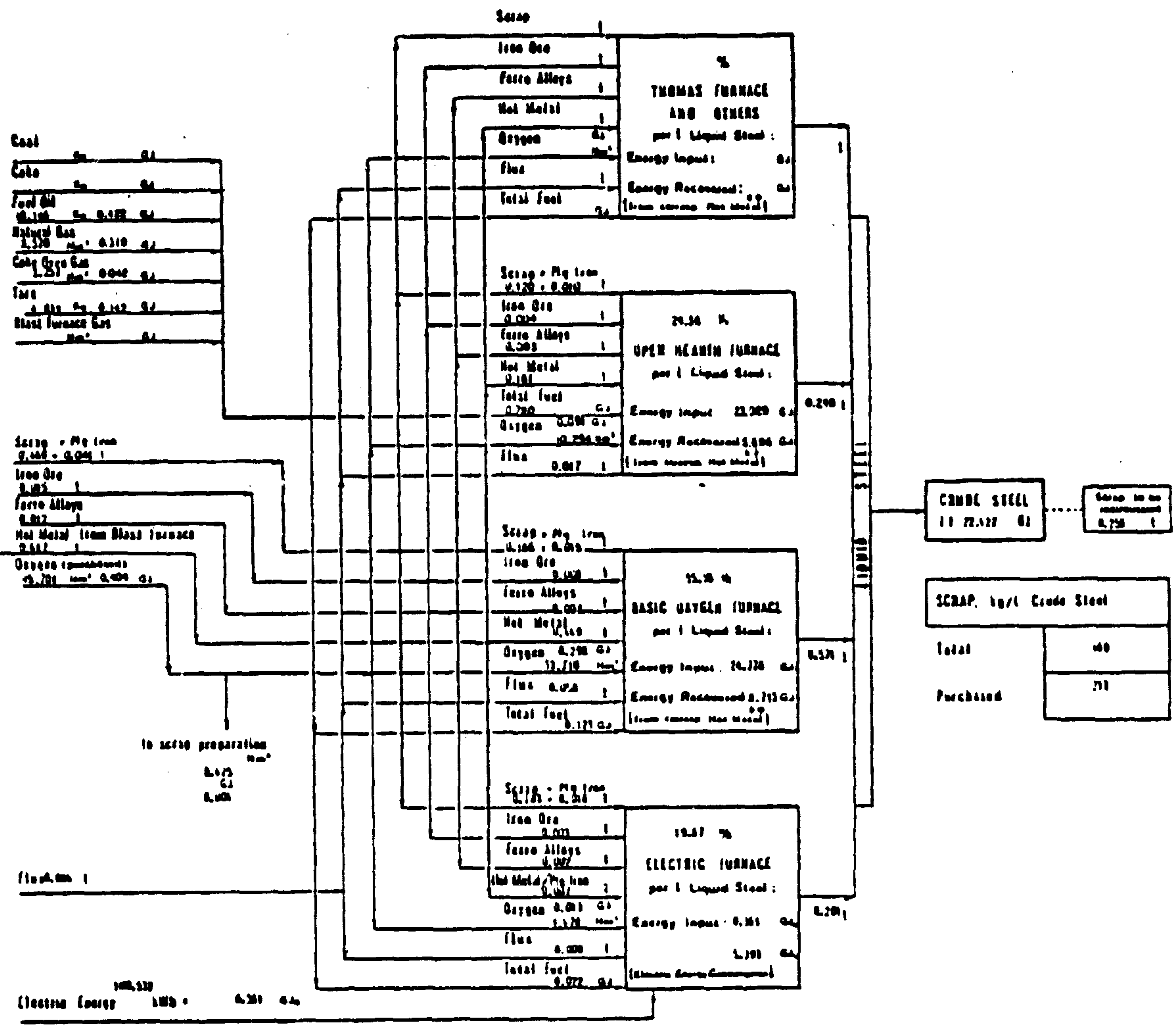
EXHIBIT 3312-16 (cont.)

MATERIALS AND ENERGY CONSUMPTION FOR THE BLAST FURNACE AND CRUDE STEEL PRODUCTION AREAS:

ONE METRIC TON OF CRUDE STEEL

(page 2)

(continued from preceding page)



Source: NATO, Committee on the Challenges of Modern Society, "Industrial Data Base - The Steel Industry," Prepared by Gordian Associates, Inc. 1977.

EXHIBIT 3312-17

ENERGY FLOWS IN SEMI-FINISHING OPERATIONS

Semi-Finishing Operation	Energy Type	Energy per Unit Product Mix 10^3 Btu
Pickle Line	Elect.	15.9
Hot Strip Mill	Elect.	194.9
Plate Mill	Elect.	44.5
Slab Reheat Furnace	Elect.	5.8
	Nat. Gas	1176.3
	Fuel Oil	3.9
	COG	371.2
Bloom Reheat Furnace	Elect.	4.1
	Nat. Gas	832.2
	Fuel Oil	2.7
	COG	262.6
Continuous Casting Billets	Elect.	1.7
	Nat. Gas	16.8
Continuous Casting Blooms	Elect.	3.4
	Nat. Gas	24.2
Continuous Casting Slabs	Elect.	4.9
	Nat. Gas	34.5
Vacuum Degassing	Elect.	8.2
Slabbing Mill	COG	913.6
	Elect.	62.0
Blooming Mill	COG	646.3
	Elect.	43.8
Ingot Casting	COG	127.8
	Elect.	7.2
Pipe and Tube Mill	Elect.	33.1
	COG	223.4
Bar Mill	Elect.	37.2

Note: COG denotes coke oven gas.

EXHIBIT 3312-17 (Continued)

ENERGY FLOWS IN SEMI-FINISHING OPERATIONS

Semi-Finishing Operation	Energy Type	Energy per Unit Product Mix 10^3 Btu
Bar Cold Finishing	Elect.	13.9
Structural/Rail Mill	Elect.	13.8
Billet Mill	Elect.	47.3
Billet Reheat Furnace	Elect.	3.4
	Nat. Gas	411.7
	Fuel Oil	14.0
	COG	205.8
Galvanizing Line	Elect.	11.8
	Nat. Gas	102.0
Tin Line	Elect.	25.3
2nd Cold Rolling Mill	Elect.	37.7
Temper Mill	Elect.	8.8
Annealing	Elect.	9.0
	Nat. Gas	110.8
	COG	7.8
	Fuel Oil	0.9
Cleaning Line	Elect.	2.4
Cold Rolling Mill	Elect.	96.1

GRAY IRON FOUNDRIES

1.0 PROCESS IDENTIFICATION

This section of the report identifies and specifically defines the industry, and provides a brief description of the current production processes employed.

1.1 SIC Classification

Gray iron foundries are classified under SIC Code 3321, which covers "establishments primarily engaged in manufacturing gray iron castings, including cast iron pressure and soil pipes and fittings". Some other major products of SIC 3321 are railroad car wheels and brakes and ductile iron castings. Establishments primarily engaged in other activities, but which also produce gray iron castings are classified under their primary SIC number.

1.2 Process Description

The process for making gray and ductile iron castings can be summarized in six general steps as follows:

1) Storage and handling of raw materials
2) Forming and preparing molds, cores and patterns.
3) Melting the metal to be cast.
4) Pouring into molds.
5) Mold cooling and shakeout.
6) Cleaning, heat treating and finishing the castings.

The major source of metallic raw material for gray iron foundries is purchased scrap iron. The purchased scrap iron may be combined with pig iron, scrap steel and ferroalloys. Depending on the type

of melting furnace used, it is possible that the scrap may have to undergo pretreatment. Metal borings often have a high oil content which has to be reduced by centrifugation to below 10% prior to melting. Induction furnaces require scrap in which the water and oil have been removed so as to preclude the possibility of explosion. Water is removed from scrap by heating to 93°C, while oil is burnt off by heating to 202-232°C. The scrap is then sometimes heated to 650°C to reduce melting time in the furnace.[1]

There are three major furnace types used in gray iron foundries. The first type of furnace is known as the cupola. A cupola is a vertical cylindrical steel furnace, which is lined with a refractory material. Metal, coke and fluxing materials (such as limestone) are charged into the top of the furnace in alternate layers. The iron is melted by the heat generated in combusting the coke. Tuyeres, located near the bottom of the furnace supply the combustion air. Liquid metal is withdrawn from the bottom of the cupola at 2762°F.[2] It is estimated that roughly 75 percent of the metal in gray iron foundries is melted in cupolas.[3]

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1. U.S. Environmental Protection Agency "Best Systems of Emission Reduction for Electric Arc Furnaces in the Gray Iron Foundry Industry," November 1975, p. 3-13.

2. Flynn and Emrich Co. "Energy Conservation Techniques for the Iron Foundry Cupola", March 1976, p. 7, prepared under contract for E.P.A., NTIS PB-256-417.

3. Battelle Columbus Laboratories, "Development and Establishment of Energy Efficiency Improvement Targets for Primary Metal Industries; SIC 33", Prepared for FEA, August 13, 1976, p. II-27.

The second major type of furnace used in gray iron foundries is the electric induction furnace. The electric induction furnace supplies heat by the action of a changing electrical flux in an induction coil which surrounds the furnace shell. An alternating current is supplied to the coil. This sets up a rapidly changing magnetic field at high flux. This changing magnetic field generates secondary currents in the metal charge which are converted to heat by the electrical resistance of the metal. Heating time is about 1 hour to 1 hour fifteen minutes.[1] Scrap for use in electric induction furnaces must be preheated and cleaned to remove water and oil to remove the possibility of an explosion hazard.

The third furnace type is the electric arc furnace. In this type of furnace, the heat is generated by an electric arc formed by passing current through the air gap between three triangularly arranged carbon electrodes and the metal charge. This is the same type of furnace used in electric steelmaking. Most of the electric furnaces used in gray iron foundries are of the induction type.

Castings are produced by pouring or injection of liquid metal into a mold. The mold is usually made of silica sand bonded together with binding materials such as bentonite, drying oils, sodium silicate and urea formaldehydes. In order to make a mold, it is first necessary to create a pattern. A pattern is an object which is shaped to the external dimensions of the desired casting. The pattern is placed in a frame called a flask which is then filled with a combination of sand and

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1. United States Steel, "The Making, Shaping and Treating of Steel." Ninth Edition, 1971, Chapter 18.

binder. When the sand/binder mixture hardens, the mold can be separated into two halves and the pattern removed. For hollow castings a core may be inserted between the two mold halves. Molds can be baked, unbaked or chemically hardened. To form the casting, molten iron is poured into the mold. When the metal has cooled sufficiently enough to solidify, the casting is cleaned in a casting shakeout. The casting is then finished by sandblasting and/or grinding. More than half of the ductile iron castings undergo heat treatment, while only a small fraction (about 10%) of the gray iron castings are heat treated. Finished castings are shipped to other industries where they are integrated into finished products.

Exhibit 3321-1 outlines the major process steps involved in producing gray and ductile iron castings. Ductile iron differs from gray iron in that it is treated with cerium or magnesium alloys. Castings produced with ductile iron have relatively higher strength and better ductility than ordinary gray iron castings.

1. Battelle Columbus Laboratories, "Development and Establishment of Energy Efficiency Improvement Targets for Primary Metal Industries; SIC 33," Prepared for FEA, August 13, 1976, Section II.

2.0 NATIONAL DATA

The annual national data presented in this section are summarized in Exhibit 3321-2. The derivation and significance of the production and energy consumption data are discussed in the following sub-sections.

2.1 Capacity and Production Data

The production figures for gray and ductile iron castings are divided into figures reflecting sales and figures reporting captive use. Since establishments primarily engaged in activities other than producing castings, but which produce some gray and ductile iron castings, are classified under the SIC Code of their primary activity, it is proper to use the "for sale" production figures collected by the U.S. Bureau of the Census. These "for sale" figures are on a comparable basis to the energy figures reported by that agency.

In 1976 14,168 x 10^3 tons of gray and ductile iron castings were produced. Of this total, 6,859 x 10^3 tons of castings were produced for sale, while the remainding castings were produced for captive use. Ductile iron accounted for 2,245 x 10^3 tons of the total production, and 1,405 x 10^3 tons of the "for sale" production reported above for 1976.[1]

There were 893 companies casting gray and ductile iron as their major products in 1972. The number of companies has been declining in recent years. In 1963 there were 1,062 companies casting gray and ductile iron, while there were 1,199 companies in 1958.[2] The eight largest companies accounted for 45% of the industry output in 1972.

1. U.S. Bureau of the Census, "Iron and Steel Foundries and Steel Ingot Producers, 1976", report M33A (76)-13, November 1977.

2. U.S. Bureau of the Census, "Statistical Abstract of the U.S.", 1977, p. 809.

Plant sizes in the gray iron foundry industry vary widely. The largest plants produce between 300,000 and 700,000 tons per year. The smallest cupola type foundries produce about 400 tons per year, while the smallest electric induction furnace type foundries produce about 300 tons per year. The average size facility produces between 5000 and 6000 tons per year. A foundry producing 400,000 tons per year would be typical of the larger size facilities accounting for the majority of the industry output.

2.2 Annual Energy Consumption

The production of gray and ductile iron castings is rather energy intensive. In 1975 when $6,397 \times 10^3$ tons of castings were produced for sale, the following consumption of energy was reported by the U.S. Census Bureau for SIC Code 3321:[1]

1975 Energy Consumption, SIC 3321

Energy Source	Consumption
Fuel Oil	2.0×10^{12} Btu
Coal	1.0×10^{12} Btu
Coke and Breeze	30.0×10^{12} Btu
Natural Gas	37.1×10^{12} Btu
Other Purchased Fuel*	10.6×10^{12} Btu
Purchased Electricity	6.5×10^{9} kWh

* Includes residual fuel oil and fuels not specified by kind.

1. U.S. Department of Commerce, Annual Survey o[illegible] [illegible]nufactures," Fuels and Electric Energy Consumed, 1975 Edition.

3.0 PROCESS ENERGY REQUIREMENTS

The sub-sections which follow describe in depth the energy consumed per unit of production in casting gray and ductile iron, as well as providing detail on the type of energy required. A summary of the energy requirements per unit of output appears in Exhibit 3321-3.

3.1 Unit Energy Consumption Data

The production of gray and ductile iron castings is an energy intensive process. The majority of the energy is consumed in melting the metal to be cast. Energy is also required for heat treating, casting finishing, mold preparation and for ancillary operations. As mentioned in Section 1.2 of this report there are several types of furnaces used in foundries. When a cupola is used, coke will be required. Purchased electric power is used to supply the energy to melt the metal to be cast when electric induction or electric arc furnaces are used. Natural gas supplies a large portion of the energy required for direct process use in gray iron foundries.

The unit of production associated with foundries is a short ton of good castings produced. This is the unit of production which was chosen by the American Foundrymen's Society and Cast Metals Federation for reporting to the Department of Energy under the Voluntary Reporting Program for Industrial Energy Conservation.

3.2 Details of Thermal Energy Consumption

Thermal energy requirements in gray iron foundries are supplied by direct fuel. Steam is used primarily to supply non-process plant needs. Steam is generally supplied at moderate temperatures and

pressures (below 300°F). Only 0.077 x 10^6 Btu of steam are required per ton of output. Hot water is generally not required for casting gray and ductile iron.

When cupola furnaces are used to melt the iron, coke is used to supply much of the thermal energy requirements. Natural gas supplies more of the thermal energy requirements than any other fuel in foundries. The direct fuel requirements per ton of output, broken down by fuel type, for an industry average plant, is presented below:[1]

Fuel Type	10^6 Btu/ton
Natural Gas	4.595
Coke	2.637
Distillate Fuel Oil	0.450
Residual Fuel Oil	0.037
Coal	0.282
Propane and Butane	0.201
	8.202

A particular plant may use any or all of the above fuels depending on its particular design. Smaller facilities may be more energy intensive than the average case presented above.

3.3 Details of Electricity Consumption

Foundries generally operate 24 hours per day seven days per week. In periods of slack demand, operating hours may be curtailed. Electric power load factors in the gray iron foundry industry will be between 0.8 and 0.9. Facilities operating electric furnaces will schedule

1. Based on personal communications with an official of the American Foundrymen's Society.

operation so as to maximize the load factor. For example furnaces will be operated alternatively so that the down time for one furance will correspond to the melting time for another furnace. This practice is used because demand charges are a very significant portion of a foundry's electric utility bill.

Gray and ductile iron foundries purchase the vast majority of their requirement for electric power from electric utilities. According to the Census of Manufactures, less than 1% of the electric energy consumed by facilities under SIC 3321 is generated on site.

An industry average foundry (exclusive of captive plants) uses 2.871×10^6 Btu of electric energy per ton of output.[1] Facilities exclusively using electric furnaces will require larger quantities of electricity.

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1. Assuming 3413 Btu/kWh.

4.0 ANTICIPATED TRENDS

This section discusses the trends which are likely to occur in the industry through the year 2000. The major emphasis is on two areas: marketing and energy consumption.

4.1 Product Growth Trends

The production figures for gray and ductile iron castings for the years 1971 through 1976 are presented below:

Year	"For Sale" Production (10^6 tons)
1976	6.859
1975	6.397
1974	8.663
1973	9.008
1972	8.190
1971	7.606

Historically the production of castings has been sensitive to general economic downturns. It is interesting to note the drop in production reported in 1975 from the previous year.

A compounded growth rate for ferrous castings of 4% per annum for the next five years has been predicted.[1] If no serious economic dislocations are to occur in the near future, a 4% annual growth rate in the "for sale" production of gray and ductile iron castings for the period 1976 to 1985 can be assumed. In this report a 2% annual growth rate between 1985 and 2000 is assumed for this industry.

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1. "American Metal Marketing", Jan. 1, 1978, p. 8.

Historical and forecast production figures are presented in graphical form in Exhibit 3321-4.

4.2 Process Changes and Implementation

The basic process for metal casting, has not changed in hundreds of years (metal is melted and poured into molds). With the emphasis in recent years on energy conservation, several new practices have been instituted to reduce unit energy consumption levels.

Electric melting furnaces are increasingly being used in favor of cupola furnaces. These furnaces are expensive to construct, however they offer decreased unit energy consumption, and are more environmentally acceptable.

Mold making may be accomplished with or without baking the mold. Newer methods of mold making use resins which make the baking of molds unnecessary (so called "cold" methods).

Increased use of insulation, using waste heat to pre-heat the charge, and electronic energy management methods all have been successfully applied to the foundry industry. Additional energy savings have been achieved by installing recuperative hot blast on some cupola furnaces, and through increased housekeeping measures.

The extent to which investment in new plants and new technology will take place, will depend on the future profitability of the industry.

4.3 Trends in Energy Requirements

In deriving the energy efficiency improvement targets for SIC 33 (primary metals), component targets were derived. The derivation of the component target for the iron foundry component of SIC 33 is shown in

Exhibit 3321-5. It was estimated that a savings of 35% in the unit energy consumption levels is technologically feasible by 1980, and a savings of 26% was both technologically feasible and economically practicable. An offset was subtracted from the gross target to allow for increased energy due to special circumstances (e.g. to comply with environmental regulations). This offset was valued at 5% of the base unit energy consumption. Therefore the net component target for the iron foundry industry segment can be estimated to be a savings of 21% by 1980 relative to 1972 energy consumption levels.

If the assumption is made that the economically practicable and technologically feasible conservation measures will be implemented by 1985, and that all technologically feasible measures shown can be implemented by 2000, then the energy consumption levels for these years can be estimated. The product growth predictions of section 4.1 were used in preparing the future energy consumption predictions, which are presented in Exhibit 3321-6.

5.0 PLANT-SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements, including indications of load profiles and reliability considerations. Several plant factors are summarized in Exhibit 3321-7.

5.1 Load Profiles

Foundries generally operate continuously, except during periods of slack demand. Electric power load factors fall into the range 0.8 - 0.9 in this industry. Plants with electric furnaces, operate furnaces alternatively in order to maximize the load factor.

The thermal-electrical coincidence factor is estimated to be 1.0 for this industry. Steam usage is very low, with steam being used continuously for non-process uses. Direct fuel thermal energy and electrical energy are required simultaneously for process uses.

5.2 Energy Flow Schematic

An energy flow schematic is presented as Exhibit 3321-8 of this report.

The schematic was derived based on the energy requirements shown in Exhibit 3321-3, and divided among end uses based on an analysis of the iron foundry industry included in the "targets" document.[1] Direct fuel use as shown in this schematic excludes the uses of coal and coke, which are shown separately.

5.3 Reliability Considerations

It is important for an iron foundry to have a reliable source of electric power. While it is unlikely that severe damage will result

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1. Battelle Columbus Laboratories, "Development and Establishment of Energy Efficiency Improvement Targets for Primary Metal Industries: SIC 33," prepared for FEA, August 13, 1976, p. II-32a.

as a consequence of a momentary power interruption, the results of an extended (several hour) interruption could be very severe. If molten material were to solidify in an electrical furnace or cupola furnace, it is possible that the refractory linings of these vessels would be ruined. Additionally, production losses involved would be considerable.

EXHIBIT 3321-1

GRAY AND DUCTILE IRON FOUNDRY FLOW SHEET

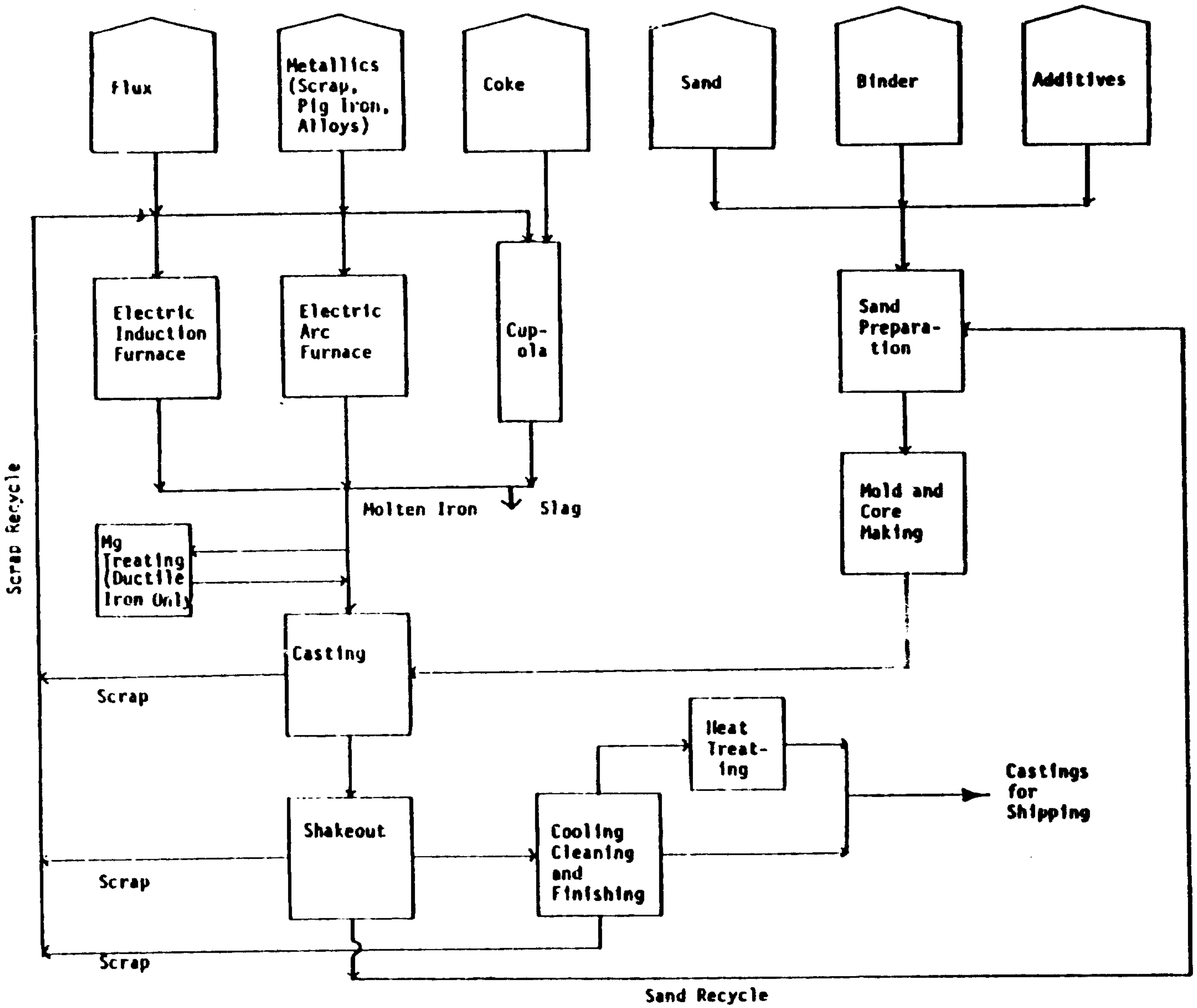

EXHIBIT 3321-2

ANNUAL NATIONAL DATA (1975), GRAY IRON FOUNDRIES (SIC 3321)

Product*** Production-Million Ton	Energy Consumption Trillion Btu	Purchased* Electricity - Trillion Btu	Purchased Fuels Trillion Btu	Coal	Oil	Gas	Other**	Total Energy Consumption For SIC Trillion Btu	Percent Total Energy Consumption Represented
6.397	103.1	22.2	80.9	1.0	2.0	37.1	10.8	103.1	100

* Purchased electricity converted to Btu at 3413 Btu/kWh.

** Includes coke and breeze (30.2×10^{12} Btu), residual fuel oil and fuels not specified by kind.

*** Total production in 1975 was $12,407 \times 10^3$ tons, however $6,010 \times 10^3$ tons were consumed captively and should not be included under this SIC Code.

EXHIBIT 3321-3

ENERGY CONSUMPTION PER UNIT OUTPUT* IN GRAY IRON FOUNDRIES

Electricity Million Btu Per Unit	Hot Water Million Btu Per Unit	Steam (Million Btu/Unit To 300°F	Steam 300-500°F	Steam Over 500°F	Direct Fuel*** Million Btu Per Unit	Exhaust Stream Temperature °F	Exhaust Stream Energy Million Btu Per Unit
2.871**	-	0.077	-	-	8.202	-	-

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* unit output denotes one ton of good castings produced.

** assuming 3413 Btu/kWh

***The industry average mix of direct fuel is as follows:

Coke	2.637×10^6 Btu/ton
Natural Gas	4.595×10^6 Btu/ton
Propane and Butane	0.201×10^6 Btu/ton
F 1 Oil	0.487×10^6 Btu/ton
C l	0.282×10^6 Btu/ton

EXHIBIT 3321-4

HISTORICAL AND FORECAST PRODUCTION OF GRAY AND DUCTILE IRON CASTINGS

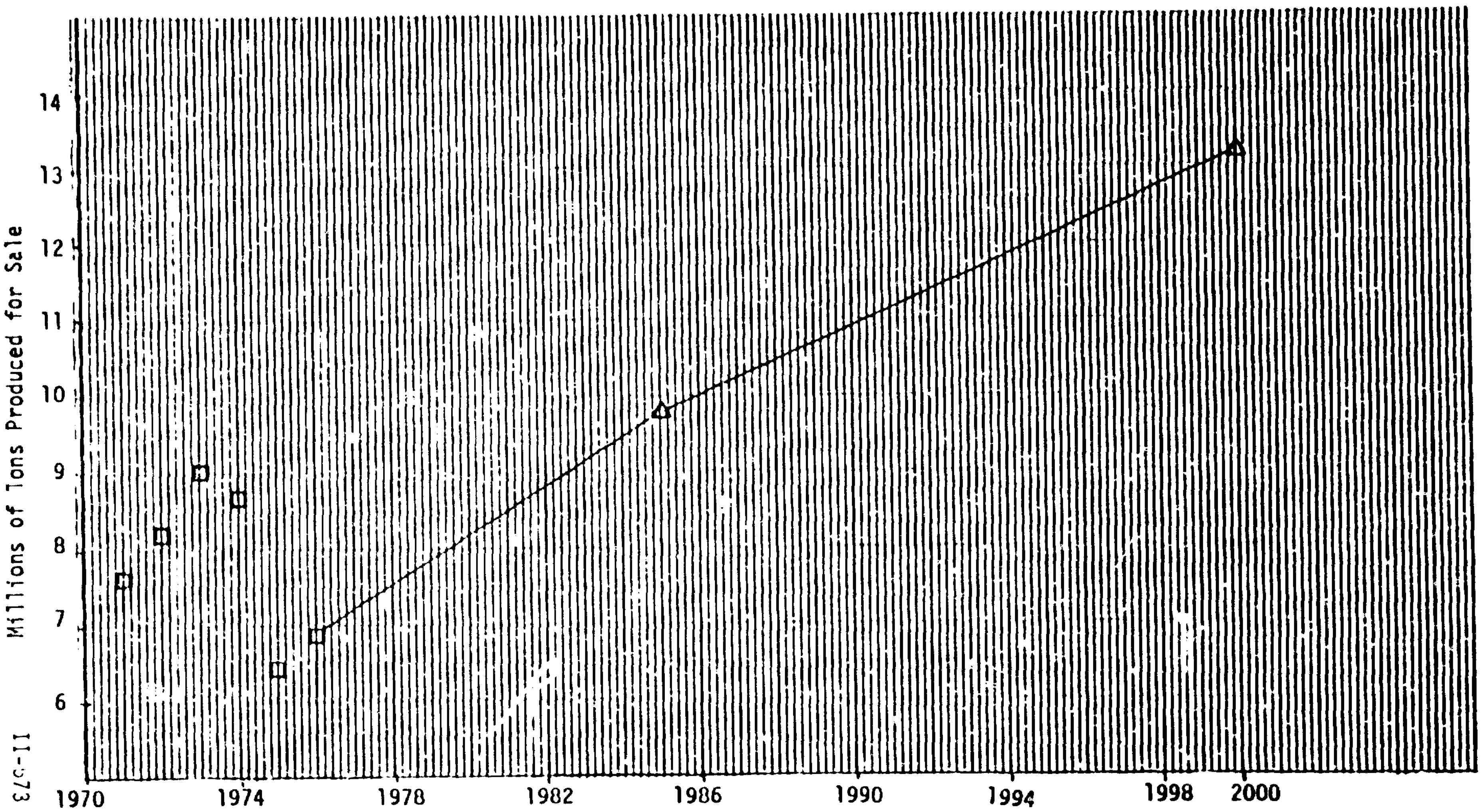

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EXHIBIT 3321-5

ENERGY EFFICIENCY IMPROVEMENT POTENTIAL BY 1980; IRON FOUNDRIES COMPONENT

Technique	Potential Saving, % Technologically Feasible	 Technologically Feasible and Economically Practicable
	%	%
Housekeeping	10.00	10.00
Increase electric melting by additional 25% of total melting	5.00	2.50
Install recuperative hot blast on additional 15% of cupola capacity	3.75	1.88
Install divided blast on additional 40% of cupola capacity	2.50	2.50
Install electronic energy-management systems in foundries making 20% of annual production	1.25	1.25
Convert additional 50% of "hot" methods for molding and coremaking to "cold" methods	6.25	3.13
Use insulating sleeves on 30% of risers	1.88	0.63
Preheat charges with waste heat for 40% of electric furnaces	1.25	0.63
Increase yield by 2% by methods in addition to above	3.75	3.75
Total	35.63	26.27

Scurce: Derived from - Battelle Columbus Laboratories, "Development and Establishment of Energy Efficiency Improvement Targets for Primary Metal Industries: SIC 33", Prepared for FEA, August 13, 1976.

C-7

EXHIBIT 3321-6

ESTIMATED ANNUAL ENERGY CONSUMPTION IN GRAY IRON FOUNDRIES FOR SELECTED YEARS

(All Data in Btu x 10^{12})

	1975[1] (Base Year)	1985[3]	2000[4]
Purchased Fuel and Electricity[2]	103.1	124.3	148.2

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(1) From Exhibit 3321-2.

(2) Electricity converted at 3413 Btu/kWh.

(3) Data for 1985 based on the following assumptions:

(a) Unit energy consumption 21% lower than in 1975.

(b) Production is 9.76 x 10^6 tons in 1985, as per section 4.1 of this report.

(4) Data for 2000 based on the following assumptions:

(a) Unit energy consumption 30% lower than in 1975.

(b) Production is 13.14 x 10^6 tons in 2000, per section 4.1 of this report.

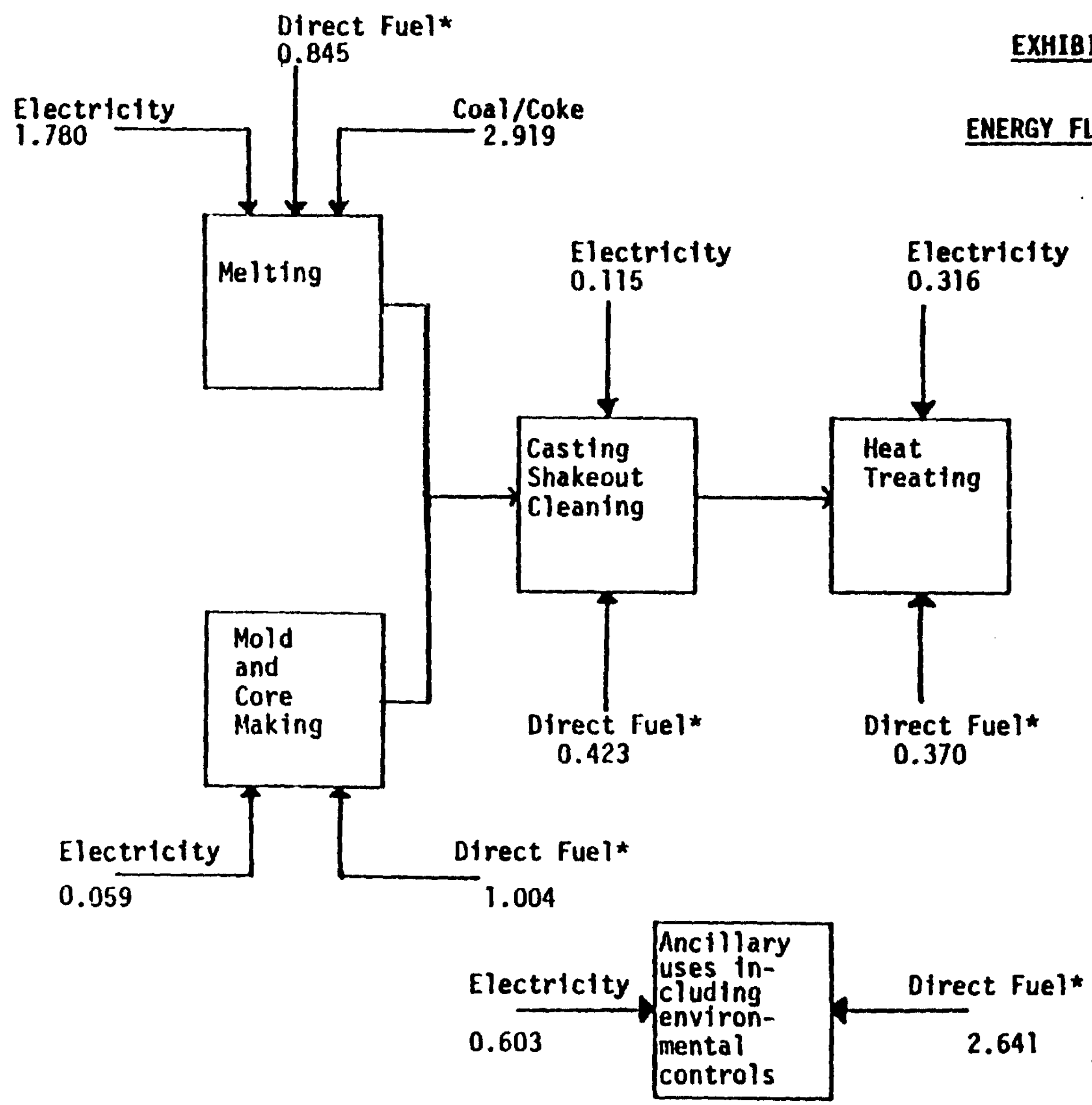
EXHIBIT 3321-7

GRAY IRON FOUNDRY PLANT FACTORS

Typical Plant Capacity Tons/Year	Plant Size Range Ton/Year	Electric Load Factor	Thermal Electrical Coincidence Factor	Projected Applicability To 2000
400,000	300-700,000	0.8-0.9	1.0	Good

EXHIBIT 3321-8

ENERGY FLOW SCHEMATIC



*Direct fuel exclusive of coal and coke.

COPPER PRODUCTION (ARBITER PROCESS)

1.0 PROCESS IDENTIFICATION

This section identifies and specifically defines the process to be studied. It should be noted that conventional copper production technology is not the subject of study, but rather a new, hydrometallurgical technique for copper extraction.

1.1 SIC Classification

The production of copper is classified under SIC code 3331, which covers "establishments primarily engaged in smelting copper from the ore, and in refining copper by electrolytic or other processes." Although the first part of this definition does not refer to the process examined herein, it is felt that the definition is sufficiently general to cover primary copper produced by any means.

1.2 Process Description

Virtually all commercial production of copper has historically been based on pyrometallurgical technology, involving the following four stages of production:

- mining
- beneficiation of ores
- smelting
- refining

The hydrometallurgical Arbiter process replaces the smelting and refining steps by electrowinning, which is a technique of extracting a metal from its soluble salt using an electrolytic cell. The salt in solution is subjected to electrolysis and is electrodeposited on a copper cathode.

As illustrated in Exhibit 3331-1, the Arbiter process consists of five separate stages. In the first stage, copper concentrates are leached at 150-175°F and near-atmospheric pressure with ammonia and oxygen. Solid residue is removed by decantation in the countercurrent decantation (CCD) thickeners, where the pregnant solution is separated. The washed residue from the last thickener is pumped to a froth flotation section for the recovery of unleached metal.

Following filtration, copper is extracted from the solution using an organic solvent. The copper-laden organic is then stripped with spent electrolyte, which is then taken to the electrowinning stage. Here, copper in the electrolyte is plated on starter sheets of pure copper to produce copper cathodes.

The Arbiter and similar hydrometallurgical processes were developed largely under the impetus of environmental pressures, as the disposal of sulfur by-products is a serious issue facing the industry. The Arbiter plant located in Montana utilizes a sulfur disposal technique known as "lime boil", although two other systems are under study. These are illustrated in Exhibit 3331-2 and described below.

The sulfur disposal method in operation involves treating the discard raffinate stream with lime and steam in a series of closed stirred tanks. The evolved ammonia is carried by steam to a fractionating tower where it is condensed and returned to the leaching process. The calcium sulfate flows as a slurry to gypsum impounding areas. Although potential markets for gypsum have been sought in wallboard manufacture, the unfavorable plant location and abundance of natural gypsum have hampered the efforts.

A second sulfur disposal method which involves the use of lime directly in the leaching system has been piloted. This largely eliminates the need for steam since gypsum is precipitated in the leaching vessels and ammonia is directly released for further reaction. The energy requirements for this option are about half of that for the "lime boil" system.

The third and possibly most attractive sulfur disposal alternative is direct crystallization and sale of ammonium sulfate from the discard stream. Markets for this type of fertilizer are under study and it is possible that this method will provide an advantage in terms of both energy use and cost.

2.0 NATIONAL DATA

The annual national data presented in this section are summarized in Exhibit 3331-3. These data refer to the entire U.S. copper industry, although the process data presented subsequently refer only to the Arbiter process, which presently accounts for only a very small part of the industry.

2.1 Capacity and Production Data

Total U.S. production of primary refined copper in 1975 was 1433 thousand tons.[1] The total has been in a steady decline since 1972 for a variety of reasons including environmental restrictions and intensified competition with other materials. Although no published figures are available on the industry's overall production capacity, it may be estimated by applying a 90% production factor to 1972 output. This results in an estimated copper refining capacity of nearly 2100 thousand tons per year.

The Arbiter process was developed by the Anaconda Company in the early 1970's, and a $22 million commercial size, 100 ton per day unit was built in Montana and started up in August, 1974. The plant shut donw in July, 1975 because of slack demand, but started up again a year later. At the present time, it is not operating.

Based on six months of production time in 1975, total output from the Arbiter plant amounted to 18,000 tons in that year.

2.2 Annual Energy Consumption

Energy consumption data reported by the Census Bureau for copper smelting and refining operations is included in Exhibit 3331-3; however, energy used in the Arbiter process is, of course, not reported separately.

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1. U.S. Dept. of the Interior, "1975 Minerals Yearbook", Volume I, U.S. Gov't. Printing Office, 1977, p. 557.

Therefore, in order to estimate the total energy used in the process in 1975, the unit energy consumption data presented in section 3.1 were multiplied by the 1975 annual production. This results in the following estimates of energy consumed in 1975 in producing copper via the Arbiter process:

	Arbiter Process	Sulfur Removal	Total Plant
	(all data in Btu x 10^9)		
Purchased electricity*	135	15	150
Natural gas**	155	401	556
Total energy	290	416	706

* At 3413 Btu/kWh

** for steam generation. Equivalent steam consumption, assuming 80% boiler efficiency, totals 445 x 10^9 BTU of steam.

3.0 PROCESS ENERGY REQUIREMENTS

This section describes in depth the energy consumed per unit of production in copper production via the Arbiter process, as well as providing detail on the type of energy required. A summary of the unit energy requirements appears in Exhibit 3331-4.

3.1 Unit Energy Consumption Data

Energy is required in the Arbiter process for leaching, extraction and electrowinning, and in the subsequent sulfur removal step for stirring, pumping, digestion and evaporation. In the process, sulfide concentrates are leached at 150-175^{o}F and near-atmospheric pressure by an aqueous ammonia solution, with oxygen piped in. Medium pressure steam at about 100 psi is utilized largely for evaporation (e.g. ammonia recovery), while electric energy is primarily used for the electrowinning step.

In the lime boil method for sulfur disposal, 100 psi steam is used for digestion of the discard stream in a closed stirred tank reactor, and for evaporation and fractionation. It has been assumed that of the total energy required for sulfur disposal, 90% is steam and 10% is electricity.*

In conventional pyrometallurgy, smelting and refining consume about 40 MMBtu per ton of copper produced (ignoring power plant inefficiencies). Fuel consumed directly in smelting accounts for about 35 MMBtu/ton of copper, and electricity for refining about 2.4 MMBtu/ton. These data are summarized in Exhibit 3331-5. It should be noted that, while the total energy shown per ton of copper is similar in the two alternatives

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* These estimates are on a fuel input basis, i.e. fuel inputs to produce both steam electricity at efficiencies of 80% and 33% respectively.

(Arbiter versus pyrometallurgy), the Arbiter process requires a higher percentage of electricity. Therefore, when power plant efficiencies are taken into account, the Arbiter process consumes more resource energy than conventional smelting and refining. In addition, the Arbiter process requires inputs of ammonia and oxygen, both of which are energy-intensive materials. These drawbacks have thus far inhibited the penetration of hydrometallurgy in the industry.

3.2 Details of Electricity and Steam Consumption

The Arbiter process is a continuous one, operating 24 hours per day. In 1975, the Anaconda plant utilizing this process operated for the first six months of the year before being shut down due to slack copper demand.

Nominal cell voltage for electrowinning is 2.1 volts per cell, with 140 cells operating. Each cell consists of 52 anodes and 51 cathodes. Current required is 24,480 amperes per cell, nominally.

The Montana plant has three 75,000 lb/hour steam boilers, two of which are used continuously. The third is utilized during the winter to meet heating loads. Steam is required at about 100 psi, and is used primarily for evaporation. During the winter, the condensate (at 110-120^{o}F) is used to keep the solvent extraction solutions warm.

4.0 ANTICIPATED TRENDS

This section discusses the likelihood of widespread implementation of the Arbiter process, and describes changes likely to occur in the process.

4.1 Growth Trends

As previously mentioned, the Arbiter process was installed by Anaconda in a 36,000 ton per year plant in August, 1974. The plant was shut down in July, 1975 due to slack copper demand, but started up again a year later. At the present time, the plant is not operating. The primary reason for this is the high cost of energy, making the process non-competitive with competing technologies. As seen in the previous section, the Arbiter process requires a more expensive mix of energy sources (i.e. higher percentage of electricity) than the conventional process route, though the total energy on a BTU basis is comparable. However, because of the nature of the energy required, the Arbiter process appears to be quite amenable to a fuel cell or other cogeneration technique. Incorporation of such a system would tend to reduce the overall energy requirement of the plant below the levels characteristic of the smelting/refining route; a previous study(1) estimates that the reduction in energy consumption through incorporation of a fuel cell would reach 37% of the energy presently required.

Of course, the future success of the Arbiter process is directly tied to the future growth in demand for copper. The U.S. Bureau of Mines estimates the probable annual growth rate for primary copper

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1. Gordian Associates, "On-Site Fuel Cell Application Evaluation", prepared for United Technologies, Inc., October 22, 1976.

through the year 2000 to be about 2.9%[1], and the Bureau's forecasts of the range and most probable demand for copper in 1985 and 2000 are shown below:[2]

FORECAST OF U.S. PRIMARY COPPER DEMAND
(thousand short tons)

	1975	1985	2000
Actual	1443	-	-
Most Probable	-	2700	4200
Low	-	-	2900
High	-	-	5300

The portion of the above demand to be attributed to the Arbiter process will be largely a function of the degree to which its operating costs (especially energy costs) can be reduced. It appears that this may be accomplished in either of two ways:

(1) use of a cogeneration system

(2) commercialization of an alternative (i.e., less energy intensive) technique for sulfur disposal.

The likely impacts of these options are discussed in the following section.

4.2 Implementation of New Technolgoy

The Arbiter process appears to be less energy efficient than conventional smelting and refining. However, a number of advantages are claimed for the process, including:

- Small minimum economic size. The smallest economic size for a conventional smelter is at least 100,000 ton/year. It is even larger for an electrolytic refinery. The Arbiter process is viable in the range of 20,000-40,000 ton/year of copper.

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1. U.S. Dept. of the Interior, "Mineral Facts and Problems", 1975 edition, U.S. Government Printing Office, 1976.

2. Ibid.

- Low capital investment per unit of output. Large smelters and refineries cost about $1200/annual ton. The smaller Arbiter plants would cost about $1000-1200/annual ton.

- The Arbiter process is truly continuous as opposed to the batch/continuous processing inherent in conventional pyrometallurgical processing. This means that the Arbiter process can be designed to have a significantly lower labor component.

- In the Arbiter process, the sulfur in the concentrate is converted to a solid by-product, which is advantageous in locations where air pollution regulations are very stringent.

Also, as previously mentioned, a number of options exist for reducing the energy consumption associated with sulfur disposal. Although precise process details are not available, estimates of the energy requirements were obtained from the originator of the process[1] as follows:

Sulfur removal route	Btu/lb*
Lime boil	12,400
Ammonium sulfate	3,500
Internal lime	7,000

* Including generation inefficiencies

Furthermore, it has previously been mentioned (Section 4.1) that incorporation of a fuel cell would reportedly reduce the plant's total energy needs by about 37%.

It therefore appears that the Arbiter process offers numerous process advantages over conventional technology in addition to potentially becoming more energy efficient. Unfortunately, slack copper demand coupled with the low price of copper and a shortage of feed materials has kept the Anaconda plant from re-starting production. Furthermore,

1. N. Arbiter, Anaconda Corp., Tucson, Arizona

a large amount of capital and effort is being expended in improving existing facilities (primarily to reduce energy consumption and air pollution), thus limiting the resources available for investment in the Arbiter process.

One recent analysis projected that 3-5 small hydrometallurgical plants will be operating in the 1980's.(1) Based on our discussions with Anaconda staff, this projection now appears unlikely. Although the existing facility will probably be running by 1985, it is doubtful that others will be built by then. It is estimated that, given suitable improvements in the energy needs of the process, three additional 36,000 ton per year facilities will be constructed by the year 2000, for a total installed capacity of 144,000 tons/year.

4.3 Trends in Energy Requirements

A prerequisite for the future success of the Arbiter process is a reduction in the overall energy cost of the process. It is likely that this will be accomplished through an alternative method for sulfur disposal. The most favorable presently existing alternative to gypsum appears to be direct crystallization and sale of ammonium sulfate from the discard stream. According to Arbiter(2), this route consumes 3500 Btu/lb (including generation inefficiencies) compared to 12,400 Btu/lb in the existing lime boil route. In fact, markets for this type of fertilizer are under study in the hope that this option will prove favorable in the future.

---

1. EPA Office of R & D, "Environmental Considerations of Selected Energy Conserving Manufacturing Process Options: Vol. XIX, Primary Copper Report", Dec. 1976.

2. Nathaniel Arbiter, "New Advances in Hydrometallurgy", presented at IGT Sumposium, Chicago, December 1974.

Based on the limited information available, it is assumed that 90% of the 3500 Btu/lb is fuel used to generate low pressure (about 100 psi) steam, or about 2.5 pounds of steam per pound of copper. The remaining 10% represents fuel used to generate electricity, or about 0.03 kWh/lb of copper. When added to the energy requirements of the Arbiter process itself, the following energy consumption per ton of copper results:

electricity (MMBTU/ton): 7.7 (at 3413 Btu/kWh)

steam (MMBTU/ton): 11.9 (in the 300-500^{o}F range)

Based on an estimated production of about 130,000 tons of copper by the Arbiter process in the year 2000, the total annual energy consumed is estimated to be:

electricity (MMBTU): 1.0×10^{12}

steam (MMBTU): 1.5×10^{12}

5.0 PLANT-SPECIFIC DATA

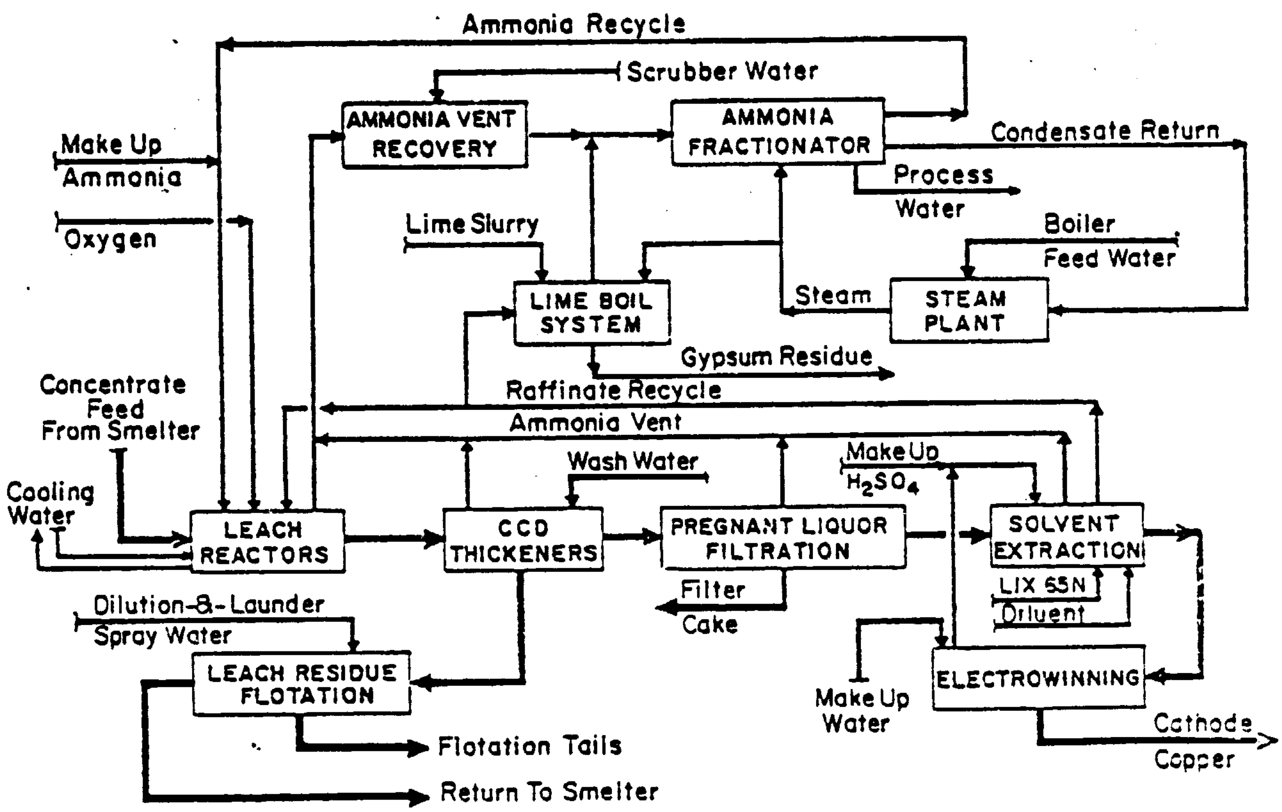
For obvious reasons, Anaconda personnel were reluctant to provide additional detail on the operations of their one Arbiter plant in existence. As a result, specific load profiles, energy flows, state conditions and mass flows are not quantified beyond the level already presented above. Exhibit 3331-6 summarizes the required plant factors.

The Arbiter process is truly continuous, as opposed to the batch/continuous processing inherent in conventional pyrometallurgical processing. Although this translates into a lower labor cost, it also implies that reliability of power supply is more critical.

With respect to process conditions, extremes are avoided. Leaching takes place at 150-175°F and near-atmospheric pressure. Steam use throughout the plant is reportedly about 100 psi. Steam is generated on-site, while all electric energy is purchased.

EXHIBIT 3331-1

ARBITER PROCESS FLOW DIAGRAM



Source: M.C. Kuhn, N. Arbiter, H. Kling, The Anaconda Company, "Anaconda's Arbiter Process for Copper", The Canadian Mining and Metallurgical Bulletin, Feb. 1974.

EXHIBIT 3331-2

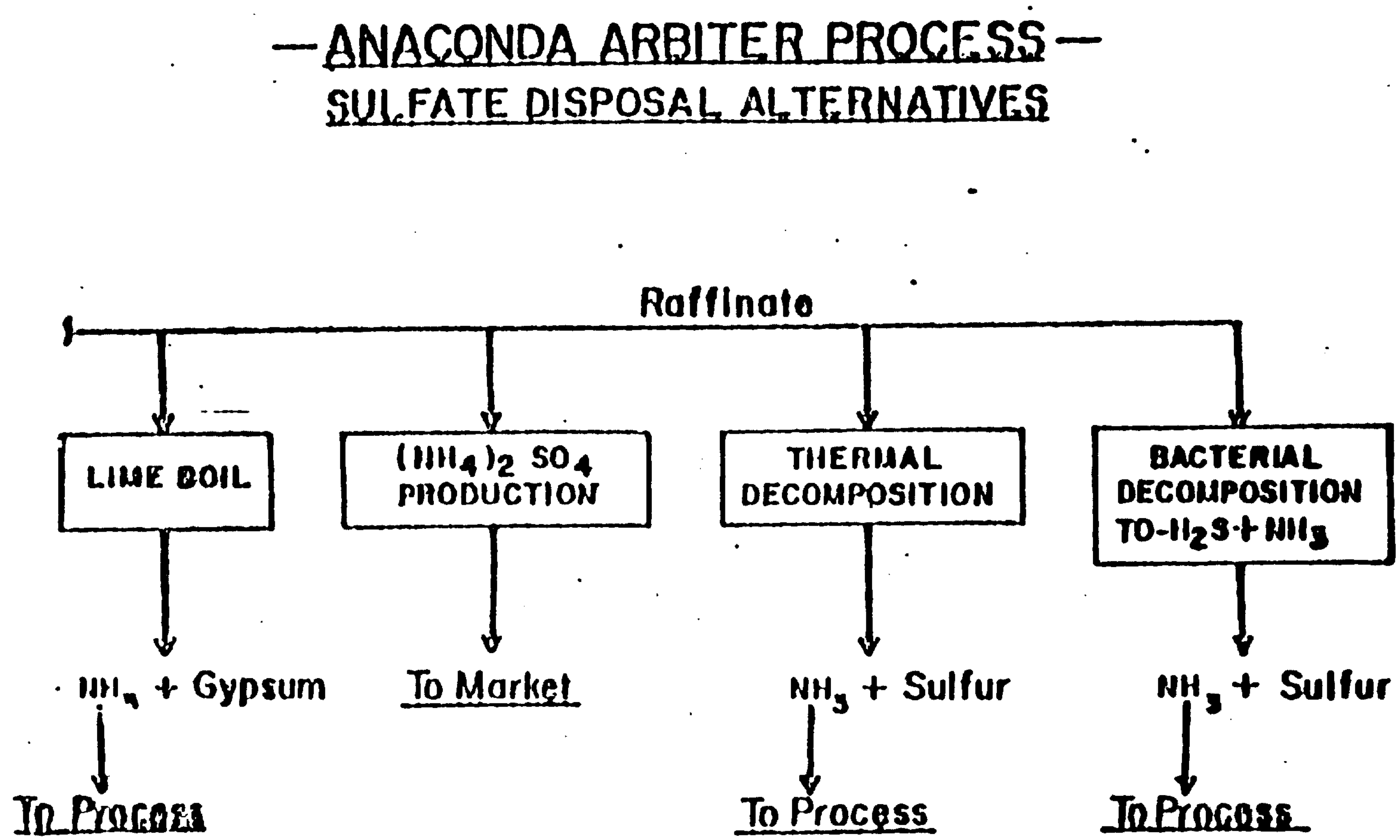


EXHIBIT 3331-3

ANNUAL NATIONAL DATA (1975), COPPER INDUSTRY

	PRODUCT PRODUCTION THOUSAND TONS	TOTAL ENERGY CONSUMPTION TRILLION BTU	PURCHASED ELECTRICITY TRILLION BTU	PURCHASED FUELS TRILLION BTU	COAL	OIL	GAS	OTHER	TOTAL ENERGY CONSUMPTION FOR SIC TRILLION BTU	PERCENT TOTAL ENERGY CONSUMPTION REPRESENTED
Total Industry	1433*	76.1	5.8**	70.3	6.0***	15.1	49.2	-	76.1	100
Arbiter Process	18	0.7	0.2	0.6	-	-	0.6	-	76.1	1

* Represents total primary refined copper

** Purchased electricity converted to BTU at 3413 Btu/kWh

*** By difference

Note: Numbers do not add due to rounding.

EXHIBIT 3331-4

ENERGY CONSUMPTION PER UNIT OUTPUT IN COPPER PRODUCTION

	Electricity Million Btu Per Ton*	Hot Water Million Btu Per Ton	Steam (Million Btu/Ton)			Direct Fuel*** Million Btu Per Ton	Exhaust Stream	
			To 300°F	300-500°F	Over 500°F		Temperature °F	Energy Million Btu Per Ton
Arbiter process	7.5	-	-	6.9	-	-	-	-
Sulfur removal	0.8	-	-	17.8	-	-	-	-
Total	8.3	-	-	24.7	-	-	-	-

* Assuming 3413 Btu/kWh

EXHIBIT 3331-5

ENERGY CONSUMPTION IN PYROMETALLURGICAL COPPER PRODUCTION

(All data in MMBTU per ton)

	Smelting	Refining	Total Process
Electricity*	0.4	2.4	2.8
Fuel	34.6	4.3	38.9
Total Energy	35.0	6.7	41.7

* assuming 3413 Btu/kWh

Source: Gordian Associates, "On-Site Fuel Cell Application Evaluation", prepared for United Technologies Inc., Oct. 22, 1976.

EXHIBIT 3331-6

COPPER (ARBITER PROCESS) PLANT FACTORS

Plant Capacity Tons/Year	Feasible Plant Size Range Tons/Year	Electric Load Factor	Thermal Electrical Coincidence Factor	Projected Applicability To 2000
36,000	20,000-40,000	90%	0.90-1.0	Excellent

MOTOR VEHICLES

1.0 Process Identification

This section identifies the standard industrial classification for the assembly of motor vehicles and provides a description of its manufacturing process.

1.1 SIC Classification

The manufacture or assembly of complete passenger automobiles, trucks, commercial cars, and buses by establishments primarily engaged in such manufacture is classified under SIC code 3711, "Motor Vehicles and Passenger Car Bodies". These establishments may also manufacture motor vehicle parts; however, establishments primarily engaged in manufacturing motor vehicle parts (except chassis and passenger bodies) are classified under SIC 3714. The manufacture of truck and bus bodies for assembly (or assembled on purchased chassis) is classified under SIC 3713.

1.2 Process Description

The assembly of a complete automobile requires precisely coordinated organization; parts, subassemblies, and process operations must be combined in the proper sequence to produce a complete product.

Assembly plants, as defined by SIC 3711, are varied in the process operations they perform. These plants may or may not include captive operations such as foundry casting, stamping, and/or machining: These basic operations, although not directly related to the actual assembly of an automobile, produce the necessary parts from which the automobile is composed.

The foundry operation produces a rough casting by pouring molten metal into a mold of the desired shape. Among the casting parts produced at an auto foundry are engine cylinder blocks, camshafts, transmissions, and chassis components.

Stamping forms metal stock (sheets, strips, etc.) into auto parts such as roof and side panels, fenders, etc.. The metal is squeezed, with tons of pressure, between two matching forms. The lower form is the "die", the upper is the "punch". Stamping operations are "blanking", "piercing", and "forming". Blanking cuts excess metal off flat stock, leaving blanks from which the part will be formed. "Forming" may be performed by a series of operations along a line of stamping or forging presses. In "forging", the blank is heated to a very high temperature, placed in a forging die, and shaped by a press or mechanical hammer.

In the machining operation cast parts are formed to the desired shape and dimensions by machines that cut away excess metal. Complex machining tools bore cylinders in engine blocks, mill and broach to provide smooth flat surfaces, and tap and ream as is necessary for a part.

The foundry and stamping operations shape parts into a rough primary form; machining and forging provide finish and final form.

The assembly of an automobile starts with building the body, which is the first feeder line in an assembly plant. Framing fixtures clamp steel body panels in place while they are welded together. Welders use electric welding machines to "spot-weld" parts together. Certain joints in the body metal are filled with solder and ground down to blend with the steel to form a smooth external surface. Finally, the car doors and deck lid are added and all surfaces are ground smooth and thoroughly cleaned.

The body is prepared for painting with a chemically applied phosphate coating. Then, certain joints are sealed with vinyl and asphalt compounds to protect against dust and water. A corrosion inhibitor is electrochemically deposited on the body in a dip tank and then oven dryed. A spray primer is applied, oven dryed, and followed by multiple coats of color enamel. The final paint-bake oven (infra-red or gas-fired) dries the paint to a hard, glossy finish.

The front end is built on another assembly line. It consists of the front fenders, radiator, grille, headlights, and fender aprons*. This finished subassembly (painted, etc.) is moved to the final assembly area where it is installed after the main body structure is attached to the chassis.

Some trimming** is done on the body at this point. Assembled on another feeder line, the instrument panels, heaters, dome lights, door panels and other interior parts are installed. At this point the body assembly is ready to join the chassis.

The chassis meanwhile, was being prepared to meet the body. On the main assembly line, axles and wheel suspensions are joined to the chassis frame. Continuing along the line, the engine, transmission and drive shaft (assembled on other feeder lines) are installed.

The body and chassis meet at the "drop" point, where the body is lowered and secured onto the chassis. At this point, the final assembly area, the front end subassembly is installed along with assemblies from

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* Fender Aprons - Inside panels at sides of the engine compartment.

** Trimming - Refers to more than ornamental chrome, upholstery and design; includes instrument panels, wiring harnesses, interior hardware, door handles, glass, heater, radio, and underbody trim (i.e., - brake lines, fuel lines, front suspension, etc.,).

other feeder lines (i.e., wheels and tires, seat assemblies, door handles, bumpers, glass, mirrors, windshield wipers, chrome, and other structures). The final checks and adjustments are made and the automobile is complete. (A simplified process flow schematic of an auto assembly plant is shown in Exhibit 3711-1.

2.0 National Data

The annual national data for the manufacture of motor vehicles is presented in this section. A summary of energy consumption and production is shown in Exhibit 3711-2.

2.1 Production Data

Summarized below is the U.S. production of passenger cars, trucks and buses by company and product line for 1974 through 1976.

PRODUCTION [3]

	1974	1975	1976
PASSENGER CARS			
American Motors Corp.	352,088	323,704	213,918
Chrysler Corp.	1,176,662	902,902	1,333,402
Plymouth	602,606	443,550	658,020
Dodge	493,993	354,482	547,916
Chrysler	110,063	104,870	127,466
Ford Motor Co.	2,205,245	1,808,038	2,053,799
Ford	1,716,975	1,301,414	1,494,054
Mercury	400,701	405,104	434,865
Lincoln	87,569	101,520	124,880
General Motor Corp.	3,585,513	3,679,126	4,891,982
Chevrolet	1,903,861	1,687,091	2,012,412
Pontiac	502,083	523,469	784,631
Oldsmobile	548,658	654,342	964,425
Buick	400,262	535,820	817,669
Cadillac	230,649	278,404	312,845
Checker	4,996	3,181	4,792
Total Passenger Cars	7,324,504	6,716,951	8,499,893

	1974	1975	1976
TRUCKS AND BUSES			
AM General	40,780	30,081	27,917
Chevrolet	867,855	773,224	1,048,125
Dodge	362,008	319,694	441,849
Ford	892,736	692,200	888,160
GMC	219,316	197,008	293,997
International	177,466	101,828	114,855
Jeep	95,757	108,065	124,924
Mack	30,999	24,597	23,230
White	28,558	11,993	17,527
Others	32,683	10,872	18,914
Total Trucks & Buses	2,748,158	2,269,562	2,999,498
GRAND TOTAL			
(Passenger Cars, Trucks and Buses)	10,072,662	8,986,513	11,497,391

Motor vehicle assembly plants typically operate 2 shifts or 16 hours per day, 5 days per week. During periods of high demand, process operations will often run into overtime for the day and increase to 6 days per week. A typical plant is estimated to produce 210,000 vehicles per year. However, depending on the product (i.e., luxury car, compact car, pick-up truck, etc.) plant production is estimated to vary from 130,000 to 340,000 vehicles per year. (2)

2.2 Annual Energy Consumption

The U.S. Census Bureau reports the following energy consumption by fuel type for SIC 3711 in 1975: (4)

1975 ANNUAL ENERGY CONSUMPTION, SIC 3711

Energy Source	Consumption (x 10^{12} BTU)
Fuel Oil	10.05
Coal*	20.17
Natural Gas	43.62
Other*	0.19
Purchased Fuel(total)	82.59
Purchased Electricity**	21.12
Purchased Fuels and Electric Energy (Grand Total)	103.71

* Coke and breeze consumption were not revealed by the 1975 Census(4) in order to avoid disclosing figures for individual companies(4) In addition, although "Other" above includes "Fuels not specified by kind" and "Other fuels" as in the Census (4), the latter was also not revealed for reasons of disclosure. As a result, the sum of the individual fuel types does not equal the total purchased fuel above.

** Purchased Electricity converted at 3413 Btu/Kwh. (Self-generated electricity was also not revealed in order to avoid disclosure).

Since motor vehicle assembly plants comprise the entire industry identified under SIC 3711, the U.S. Census Bureau data reported for this SIC is considered entirely representative of that industry.

3.0 PROCESS ENERGY REQUIREMENTS

The following sub-sections describe the thermal and electrical requirements per unit of production for motor vehicle assembly plants. A summary of energy requirements per unit output is presented in Exhibit 3711-3.

3.1 Unit Energy Requirements

As mentioned in Section 1.2, motor vehicle assembly plants may differ from each other in the process operations, indirectly related to assembly, that they may perform. Such diversity may include process operations like stamping, casting, machining, and other processes.

As a matter of convention for this section those assembly plants integrated with other operations (i.e., casting, machining, etc.) and those assembly plants specializing only in assembly are referred to as diversified and non-diversified, respectively.

The unit energy requirements for the industry as a whole including both diversified and non-diversified plants are presented below:

UNIT ENERGY REQUIREMENTS

(1975 - Industry Composite)

	Motor Vehicle Assembly - SIC 3711
	MM Btu/Vehicle
Electricity*	2.35
Steam**	5.74
Direct Fuel (Natural Gas)***	2.02
Total	11.54

---

* Electricity converted at 3413 Btu/kWh.

** Assuming an 80% boiler efficiency, fuel consumed to produce steam represents 7.17 MM Btu/Vehicle.

*** Direct fuel (natural gas) is (2) estimated as 22% of the total fuel consumed on a Btu basis.

Additionally, for a typical non-diversified assembly plant specializing in assembling prefabricated parts only, the unit energy requirements are shown below: (2)

UNIT ENERGY REQUIREMENTS (2)

(1977 - Motor Vehicle Assembly Plant (non-diversified))

	MM Btu/Vehicle
Electricity*	1.2
Steam	2.8
Direct Fuel (Natural Gas)	0.9
Total	5.6

3.2 Details of Energy Consumption

Motor vehicle assembly plants usually operate 16 hours per day, 5 days per week; however, depending on market demand, process operation may run into overtime exceeding 16 hours per day and may even warrant 6 days per week operation.

In considering energy consumption details it should be realized that only 55-65% of the total energy is used for process operations.[2] HVAC** consumes a large portion of the plant energy: in a typical assembly plant HVAC is estimated to consume 30% of the total energy and 23% of all the electrical energy. [2] Lighting is estimated to consume 22% of the total electrical energy. [2]

Besides HVAC and lighting, the primary electric energy consuming operations are: compressing air for driving pneumatic tools, painting, welding, and driving conveyors and hoists. A breakdown of electric energy consumption for a typical non-diversified assembly plant is shown below: [2]

---

* Electricity converted as 3413 Btu/kWh.

** HVAC: Heating, Ventilating, and Air-Conditioning.

TYPICAL BREAKDOWN of ELECTRICAL LOAD (2)

ASSEMBLY PLANT

Painting	29%
HVAC	23%
Lighting	22%
Compressed Air	14%
Welding	8%
Conveyors & Hoists	4%

The painting operation involves the electrolytic coating of a corrosion inhibitor, the manufacture of chilled and cleaned compressed air for spraying, and the drying of the paint, either electrical (infra-red lamps) or thermal (natural gas fired directly or, in some old plants, steam).

Natural gas is also indirectly used to provide heated fresh air for circulation in the spray booth atmosphere. (Older plants use steam in their air make-up units but natural gas is more prevalent).

Steam is primarily used for HVAC, approximately 80% of the heating requirement alone is met by steam. [2] Other uses for steam are liquid heating (which accounts for about one-third of the total steam usage) and steam cleaning the car body prior to painting. [2] Also, in assembly plants integrated with other operations (stamping, casting, machining), steam may be used to drive stamping presses. Plant steam pressures vary from 100 psig to 150 psig.

4.0 Anticipated Trends

This section discusses trends through the year 2000. The major emphasis is on market development and trends in process technology and energy consumption.

4.1 Product Growth Trends

The automobile plays an important role in the American life style: socially, economically, and environmentally. Hence, the industry is subject to legislation regulating fuel consumption, safety and emissions (in addition to its sensitivity to market demand factors). The factors of major impact on the industry are:

- Fuel economy regulations. Federal fuel economy standards to be complied with in 1985 are for passenger automobiles: 27.5 mpg and for light duty truck and van motor vehicles: 22 mpg. Vehicle weight reduction and technological innovation in engine design are expected to accomplish the majority of progress towards these goals. (5)

- Emissions standards, also to be met by technological innovation in engine and exhaust system design (as well as vehicle weight reduction, allowing smaller engines to be used).

- Vehicle safety standards, concerning accident prevention, occupant protection, and post-accident protection (i.e., air bags, upgrading protection of steering control system, improving front and side occupant protection, rollover occupant protection, improved door locks and door retention components, reduced flammability, and toxicity of interior ornaments, etc.).

The final effect of such federally mandated standards will be the willingness of the consumer to absorb their additional cost.

Other factors, also expected to affect SIC 3711 product growth trends are the increasing use of mass transit and the potential of a national fuel rationing plan in the event of a fuel shortage.

An assessment of these factors in order to predict motor vehicle sales* to the year 2000 would be difficult to quantify. However, two predictions were made, one by a linear regression method of extrapolation and the other by utilizing a historical average ratio of motor vehicles per dollar of GNP** in conjunction with a predicted GNP growth rate, assumed at 2.3% per year***. The motor vehicle sales forecasts to 1985 and 2000 resulting from both prediction methods are shown below and in Exhibit 3711-4.

MOTOR VEHICLE SALES
(millions of motor vehicles)

Historical			Forecast	
1975	1976		1985	2000
8.99	11.45	Linear Regression	13.73	17.36
		Per GNP	14.56	20.48

4.2 Process Changes and Implementation of New Technology

In order to meet mandated future fuel efficiency standards while maintaining an acceptable emissions level, a variety of technological options are under study.

The engine designs most likely to be adopted to improve fuel economy are the lean burn, stratified charge, and diesel engines. (5)(6) Other engines, such as the gas turbine and stirling cycle engines, require major technological breakthroughs for the development of production designs. The electric engine requires a technological breakthrough in the area of electric storage systems. (6)

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* Since historical production data as far back as 1950, was not available, sales data was used instead. Sales and production quantities are so close that the difference is negligible.

** GNP - Gross National Product, used here as "Real GNP" in 1972 dollars.

*** Gordian Associates estimate.

Other options for improved fuel economy are electronic engine controls, electric cooling fans, turbo-charging, four speed automatic transmissions, improved lubricants, reduced tire rolling resistance and aerodynamic drag, and vehicle weight reduction (allowing for the use of lower displacement engines). [5]

In reducing vehicle weight it is expected that approximately 15% of the sheet steel in the automobile's body panels and interior parts will eventually be replaced by plastic and aluminum. In addition, 10% by weight of cast iron will be replaced by cast aluminum (for brake drums, intake manifolds, water pumps, disc brake rotors, etc.,) and reduced thickness of glass and/or substitutions with lighter plastics is expected to reduce total glass weight by 15%. The use of a minispare tire (expected in the early 1980's) and the development of a "run-flat" tire (late 1980's) will further reduce or eliminate spare tire and rim weight. [5] Finally, the trend towards smaller cars will reduce the energy consumed per vehicle manufactured. (8)

In considering all these potential technological options, it should be realized that their development will depend on the cost and risk to the manufacturer, the extent of government intervention, and their marketability and cost to the consumer.

4.3 Trends in Energy Requirements

In developing an energy conservation target for the Department of Energy for SIC 37, an energy conservation target for SIC 371 of 16% for 1980, relative to 1972 energy consumption level was estimated. [7]

Based on this target and the available energy conservation measures, it was assumed that an equivalent 16% reduction in unit energy consumption

could be achieved by 1985, relative to 1975. Since energy costs represent a relatively significant portion of the total operating costs of an assembly plant, it is likely that substantial effort will continue to be devoted to energy conservation in the future. We have assumed a 15% reduction in energy needs in 2000 relative to 1985 levels.

The total estimated energy consumption, including a breakdown showing fuel and electric energy consumed,, through the year 2000, is presented below:

Estimated Energy Consumption Trends, 1975-1985-2000

Motor Vehicle Manufacture

$x10^{12}$Btu	1975	1985	2000
Total Purchased Fuel and Electricity	103.7	133.1	138.2
Purchased Fuel	82.6	106.0	110.1
Purchased Electricity*	21.1	27.1	28.1

Assuming an 80% boiler efficiency for steam generation and that natural gas, used directly represents 22% of the total fuel consumed on a Btu basis (2), the utility consumption through 2000 is shown below:

Utility Consumption - 1975-1985-2000

Motor Vehicle Production

$x\ 10^{12}$Btu	1975	1985	2000
Electricity*	21.1	27.1	28.1
Steam (@ 100 to 150 psig)	51.5	66.1	68.7
Natural gas	18.2	23.3	24.2

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* At 3413 Btu/kWh.

5.0 Plant Specific Data

This section provides available data relating to specific plant energy requirements, load profiles, state conditions, and reliability considerations. Several plant factors are summarized in Exhibit 3711-5.

5.1 Load Profiles

Motor vehicle assembly plants usually operate 16 hours per day, 5 days per week; however, depending on market demand, operation may exceed 16 hours per day and jump to 6 days per week. The electric load factor for the operating time period is estimated at 90%, [2] this in combination with the shutdown electric load factor of 20% [2] gives an estimated electric load factor of 70% overall. Of course, if market demand increases the typical operating schedule, the electrical load factor will exceed 70%.

The thermal-electrical coincidence factor is estimated as greater than 0.90 for the operating and shutdown time periods since even during shutdown hours, lighting and a 55°C temperature is maintained for office operation. (8) (2)

5.2 Energy Flow, Mass Flow, and State Conditions

As mentioned in section 3.2, motor vehicle assembly plants use electricity, steam, and natural gas (as a direct fuel). Only 55-65% of the total energy consumed is used directly by the process, with the remaining energy used to maintain HVAC and lighting. [2] In addition (as discussed in section 3.1), assemblv plants may be integrated with other operations (i.e., stamping, casting, machining, etc.,) which, although

not directly related to assembly, may vary the relative consumption of electricity, steam, and natural gas among the different plants classified under SIC 3711.

Steam, varying between 100 to 150 psig, is used primarily for HVAC. Other uses include steam cleaning car bodies prior to painting, spray booth air make-up units* (in older plants), and paint bake ovens (also, in older plants).

Natural gas, as a direct fuel, is used primarily in spray booth air make-up units* and in paint bake ovens. Its use for these operations is considered prevalent compared with steam used for the same operations in some older plants.

Electricity is used to drive the highly automated operations of an assembly plant. Besides HVAC and lighting, which are major ele-tricity consumers, it is used for an electrochemical painting process, compressed air, welding, for driving conveyors and hoists.

The assembly process is a precisely organized and timed operation; the proper part (and/or subassembly) must reach the in process motor vehicle exactly when needed. On the average, the assembly plants within SIC 3711 are estimated to produce 50 cars per hour; [2] however, plants range from 30 to 80 cars per hour depending on the product line (i.e., luxury car, pick-up truck, subcompact, etc.). (2) The estimated time to produce a car at an assembly plant is approximated 3-4 shifts (24-32 hours or 2 working days). [2]

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* <u>Spray booth air make-up units</u> - provide heated, fresh air for circulation in the paint spray booth.

5.3 Reliability Consideratons

The manufacture of a completely assembled automobile is a highly labor intensive process. Hence, due to the nature of the process, the consequences of a total power failure would result primarily in economic damage.

Upon resuming power, the estimated start-up time is 1-2 hours. [2] No equipment damage is expected; however, in process product may be damaged at the electrolytic corrosion inhibitor coating process. Other than that, with an air purge of the natural gas paint bake ovens (to prevent explosion of accumulated solvent vapors) operation would resume smoothly.

EXHIBIT 3711-1

MOTOR VEHICLE ASSEMBLY PLANT - PROCESS FLOW DIAGRAM

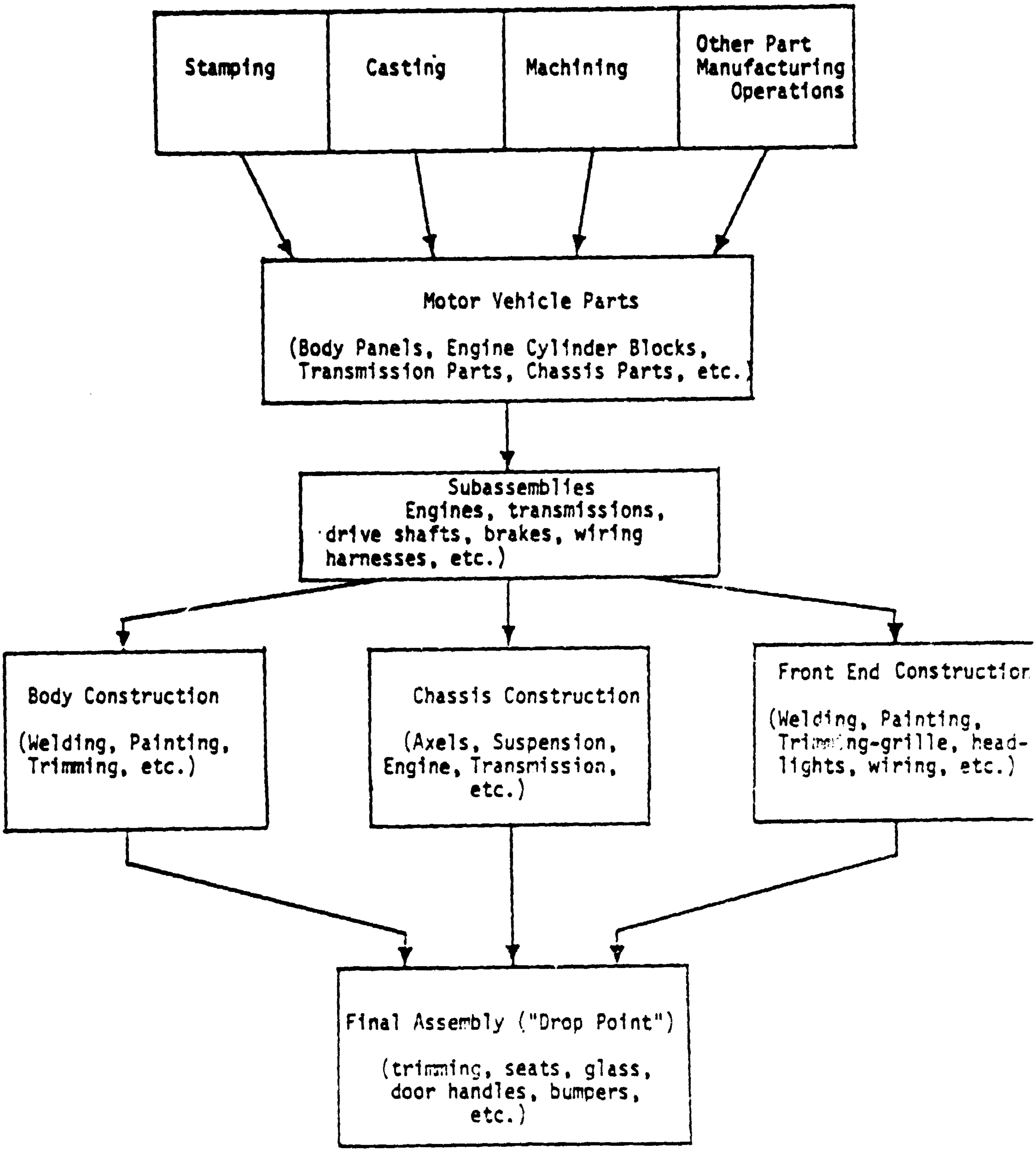

EXHIBIT 3711-2

ANNUAL NATIONAL DATA (1975), SIC 3711 - MOTOR VEHICLES

Product Production Million Motor Vehicles	Total Energy Consumption Trillion Btu	Purchased** Electricity Trillion Btu	Purchased Fuels Trillion Btu	Coal*	Oil*	Gas*	Other*	Total Energy Consumption for SIC Trillion Btu	Percent Total Energy Consumption Represented
9.0	103.71	21.12	82.59	20.17	10.05	43.62	0.19	103.71	100%

* In the 1975 Census of Manufactures "Coke and Breeze" consumption was not revealed in order to avoid disclosing figures for individual companies. In addition, although "Other" above includes "Fuels not specified by kind" (from the 1975 Census), "Other Fuels from the Census was also not revealed for reasons of disclosure. As a result, the sum of the individual fuel types does not equal the purchased fuel total above.

** Purchased electricity converted at 3413 Btu/kWh.

EXHIBIT 3711-3

Energy Consumption Per Unit Output: Motor Vehicle Production

Electricity* Million Btu Per Vehicle	Hot Water Million Btu Per Vehicle	Steam** (Million Btu per Vehicle)			Direct Fuel Million Btu Per Vehicle	Exhaust Stream	
		To 300° F	300-500°F	Over 500°F		Temperature °F	Energy Million Btu Per Vehicle
2.35	--	--	5.74	--	2.02	--	--

* Electricity at 3413 Btu/kWh

** Derived from boiler fuel at an 80% boiler efficiency

Note: The above data pertains to an industry composite as developed from the 1975 Census of Manufactures. For the energy requirements of a typical assembly plant, specializing in only assembly operations, see Section 3.2.

EXHIBIT 3711-4

MOTOR VEHICLE SALES

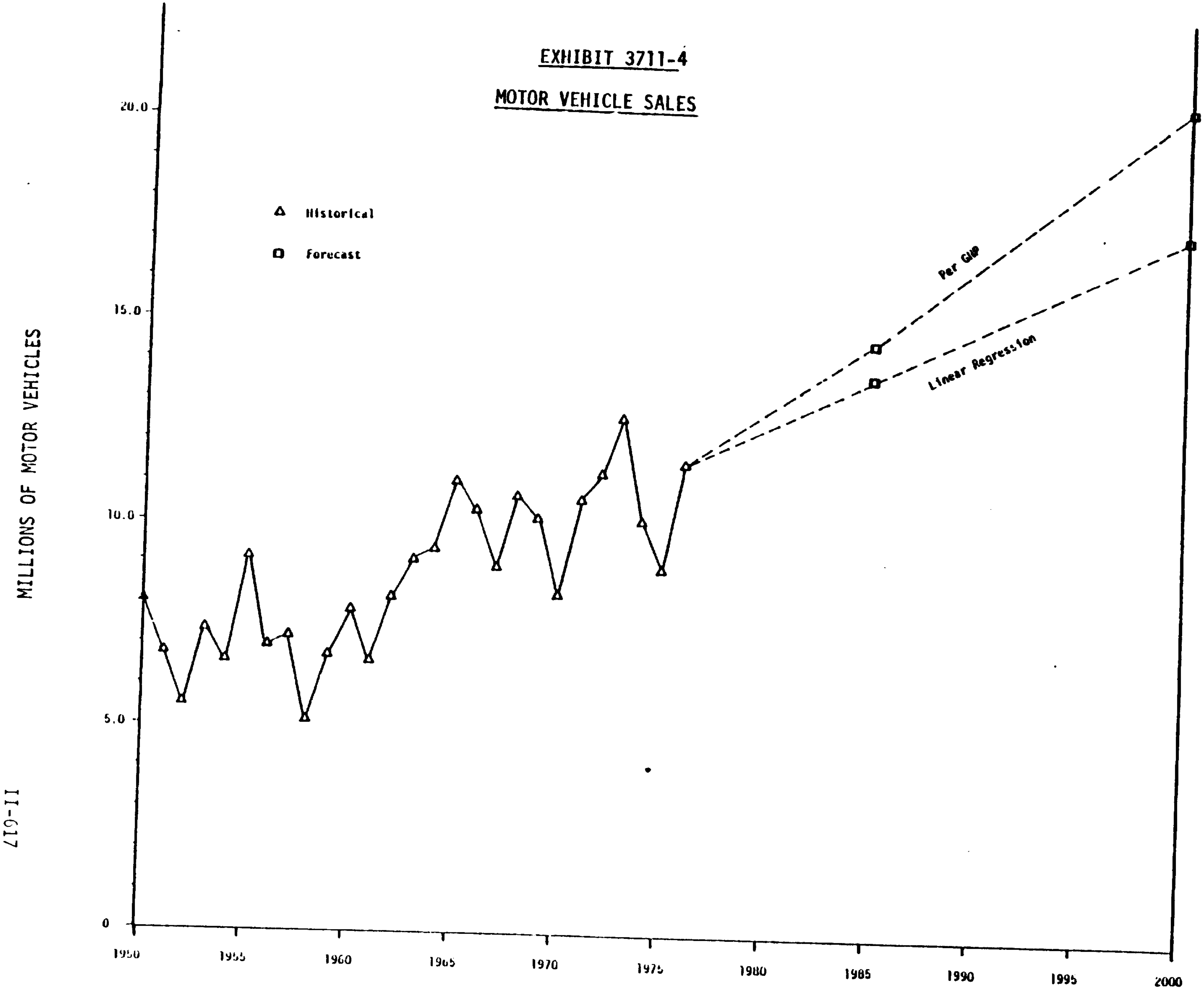

EXHIBIT 3711-5

Motor Vehicle Manufacturing Plant Factors

Typical Plant Capacity Vehicles/Year	Plant Size Range Vehicles/Year	Electric* Load Factor	Thermal** Electrical Coincidence Factor	Projected Applicability To 2000
210,000	130,000 340,000	>70%	>0.90	Good

* Motor vehicle assembly plants usually operate 16 hours/day, 5 days/week but depending on market demand operation may increase to 16 hours/day plus overtime and 6 days/week. For the operating time period the electrical load factor is estimated at 90% and for the shutdown period it is estimated as 20%. Since motor vehicle production has the potential to increase with market demand the combined factor (operating and shutdown period) is stated as in excess of 70%.

** The thermal-electrical coincidence factor is also a combination of the operating period factor (0.90) and the shutdown period factor (0.00).

FOOTNOTES

(1) "Know How, What it Takes to Make Your Car", Motor Vehicle Manufacurers Association, Detroit, Michigan.

(2) Private communication with industry representatives

(3) "Motor Vehicle Facts and Figures '77", Motor Vehicle Manufacturers Association, Detroit, Michigan.

(4) U.S. Department of Commerce, Bureau of Census "Annual Survey of Manufacturers, Fuels and Electric Energy Consumed", 1975

(5) "Trends in the Automotive Industry Through 1990", A.D. Little, Inc., Cambridge, Massachusetts, May, 1978.

(6) U.S. Department of Commerce, "U.S. Industrial Outlook 1977 with projections to 1985," pp. 165-177

(7) A.T. Kearney, Inc., "Energy Efficiency Improvement Target, Transportation Equipment Industry (SIC 37)", Federal Energy Administration, July 13, 1976.

(8) A.T. Kearney, Inc., "Industrial Energy Study of the Motor Vehicles Industry", Federal Energy Administration (National Technical Information Service, U.S. Dept. of Commerce), July 1974.

GLASS CONTAINER PRODUCTION

1.0 PROCESS IDENTIFICATION

This section identifies and specifically defines the industry, and provides a brief description of the current production process employed.

1.1 SIC Classification

The production of glass containers is classified under SIC code 3221, which covers "establishements primarily engaged in manufacturing glass containers for commercial packing and bottling, and for home canning." This classification includes a variety of glass bottles, jars, and other containers.

1.2 Process Description

The manufacture of glass containers occurs in five phases:

1. Batch handling
2. Melting and fining
3. Forming
4. Post-forming
5. Product handling

These operations are illustrated in the process flow diagram (Exhibit 3221-1), and are described more fully below.

The function of the batch handling operation is to prepare and feed to the melting tank a batch which is both chemically and physically uniform in composition. The major ingredients of the glass batch are sand, soda ash, limestone and feldspar. In addition, cullet (scrap glass) collected from the plant or from recycling centers is added. Cullet assists in the melting process because it liquefies at a lower temperature than the other raw materials, providing a molten bath which

helps transfer heat to other materials. The molten batch is heated to about 2800°F by directing flames across the top surface. Time is then allowed for entrapped bubbles to rise and leave; this is known as "fining".

Considerable energy savings are made by using regenerative furnaces, which operate in two cycles. At opposite sides of the furnace are chambers known as checkers. As illustrated in Exhibit 3221-2, combustion gases, after passing over the molten batch, continue out through one set of checkers. At regular intervals, the flow is reversed and the cold fuel-air mixture passes through the heated checkers and out the other side.

As molten glass flows continuously from the furnace it drops through a "gob-feeder", where the glass is cut into gobs of the desired size. Delivery equipment then directs the gobs into blank molds, where the bottle is shaped with the aid of compressed air.

After forming, the bottle undergoes post-forming operation, including surface treatment, annealing, decorating and coating. The primary step involved is annealing, which is necessary to remove stresses in the glass. The container is brought to a uniform temperature of 1100-1200°F in order to relieve internal stresses by plastic flow and then cooled at a uniform rate to prevent development of new stresses. Annealing is done in long continuous ovens called lehrs, which are the primary energy consumers in the plant, next to the melting furnace.

Finally, containers are polished, coated, and visually or optically inspected as they are conveyed to packing machines.

2.0 NATIONAL DATA

The annual national data presented in this section are summarized in Exhibit 3221-3.

2.1 Capacity and Production Data

In the U.S., there are 25 major container manufacturers operating 117 plants, with the five largest companies operating nearly half of these(1). The manufacturers, along with the number of plants operated by each, are listed in Exhibit 3221-4.

Geographically, glass container plants are located near the markets they serve. Plants are situated throughout the U.S., but a large number are concentrated in the East North Central and Middle Atlantic States. The regional distribution of the major plants is shown in Exhibit 3221-5.

Production of glass containers in 1976 reached 26,032 million pounds, up from 25,338 million pounds in 1975(2). Based on 117 plants, the average plant production is therefore 222 million pounds per year. Assuming a production/capacity ratio of 90 percent, the industry mean production capacity is estimated to be roughly 250 million pounds per year.

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(1) Battelle Columbus Laboratories, "Industrial Energy Study of the Glass Industry", Federal Energy Administration, Dec. 1975, p.80.

(2) Glass Packaging Institute, Washington, D.C., 1977 report.

2.2 Annual Energy Consumption

The U.S. Census Bureau reports the following consumption of energy in 1975 and 1976 by SIC code 3221:[1]

ENERGY SOURCE	CONSUMPTION	
	1976	1975
Fuel Oil	26.4×10^{12} BTU	24.3×10^{12} BTU
Coal	-	-
Natural Gas	104.3×10^{12} BTU	101.5×10^{12} BTU
Electricity	4497.1×10^{6} kWh	4151.5×10^{6} kWh

As shown, natural gas is by far the dominant energy source, providing over 70% of the input energy for production. Oil accounts for about 18% and electricity about 10% of the energy consumed.

(1) U.S. Dept. of Commerce, "Annual Survey of Manufactures", Fuels and Electric Energy Consumed, 1975 and 1976 editions.

3.0 PROCESS ENERGY REQUIREMENTS

3.1 Unit Energy Consumption Data

Within a glass container plant, the total amount of energy used, as well as the energy used for each process step, will depend upon many factors. Generally, however, the range of energy consumed in each process step falls within certain limits. The ranges are given in Exhibit 3221-6. As shown, melting accounts for about 70 percent of the total energy needed for glass production.

Exhibit 3221-7 shows how the energy would be distributed in an average plant, where all of the energy was supplied from natural gas and electricity. Propane could be substituted directly for the natural gas in any of the areas shown; however, oil could only be substituted or used in 59 percent of the melting and fining operation (in the melting end of the furnace).

The average energy usage per ton of glass containers shipped in 1975, based on the information in Exhibit 3221-3, was 9.9 x 10^6 BTU of fuel plus 32.76 kWh of electricity. Exhibit 3221-8 presents these and other unit consumption data for glass container production.

3.2 Details of Electricity Consumption

As was illustrated in Exhibit 3221-7, electricity is consumed in every process step in varying quantities. It is used to drive electric motors for conveyers, mixers and combustion fans in the melting, forming and post-forming operations. It is sometimes used to supply process heat for melting and for some post-forming operations. It is also used for the lighting and space conditining of plants, and for generating compressed air.

In electric melters, the glass is heated by its own self-resistance by passing an electric current throught it. Because the energy is supplied internally to the glass, there is much less energy loss than with fuel-fired melters. However, when the energy needed to produce the electricity is considered, the total Btu's consumed is approximately the same in both cases.

Many fossil fuel-fired furnaces are electrically boosted in order to obtain increased production from existing facilities. Usually, 5 to 10 percent of the total energy input to the melter is supplied via boosting, and boosting can be reduced or turned off as demand fluctuates.

The glass industry operates its furnaces seven days a week, continuously. Hence, load factors are high and variations on a daily, weekly, or seasonal basis are small.

3.3 Details of Tharmal Energy Consumption

Thermal energy consumption in glass container production is limited to direct fuel firing and there is no process steam used. Temperatures in the melting furnace reach 2800°F, and in the annealing lehrs 1200°F.

Despite the regenerative furnace design, large quantities of heat are rejected to the atmosphere in glass production. Heat rejection from the melting furnace alone due to radiation is about 3.4×10^6 Btu per ton of glass, and the stack gases contain an additional 1.4×10^6 Btu/ton of glass at 1000°F.(1) The heat rejected during glass cooling amounts to an additional 2.0×10^6 Btu/ton. These losses require substantial capital investment and/or design modifications to be reduced.

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(1) Dow Chemical Co., "Energy Consumption: Paper, Stone, Clay, Glass, Concrete, and Food Industries", National Environmental Research Center, April, 1975, p.22.

4.0 ANTICIPATED TRENDS

This section discusses the trends which are likely to occur in the industry through the year 2000.

4.1 Product Growth Trends

During the past decade, the compound growth rate in glass container production has averaged about 4.6% per year. However, since 1970, the rate has averaged only 1.4%. This is indicative of the large inroads which are being made by environmentalists, causing a resurgence in returnable bottles and increased attention paid to recycling of glass. Regulations banning non-returnable containers are, at the present time, being considered in a number of states, following the passage of the "bottle bill" in Oregon. While these laws increase the market share of glass containers, they do not necessarily boost production, since one returnable bottle replaces 10-15 disposable bottles, on average. Thus, it is not likely that historical levels of production growth can be maintained in the future. Assuming a growth rate of two percent per year through 1985 and 1.5 percent per year thereafter results in the following projections of glass container production:

Year	Million Tons
1976	13.02
1985	15.6
2000	19.5

4.2 Process Technology Changes and Implementation

Historically, a recurring problem with raw materials has been the necessity for maintenance of a homogeneous batch in the solid state before melting. Local demixing or inhomogeneities in the batch are

reflected in the final product, by the formation of defects known as "cords". Cords differ from the mass of the melt as to chemical composition and physical properties. In an effort to avoid cords, some research has been done towards using finer raw materials and subsequently pelletizing or briquetting the fine materials prior to charging the furnace. A by-product of this research has been the demonstration that finer raw materials require less energy for melting, and furthermore, the use of pellets affords the possibility of utilizing waste heat to preheat the pellets prior to their introduction into the furnace.

FMC Corporation has recently announced a new briquetting process for lowering temperature in glass furnaces while maintaining the same production rates; Corning Glass Works and Battelle Columbus Laboratories are doing similar work.[(1)] Although FMC's process has not been tried commercially, it reportedly can reduce energy requirements in current operation by 25%. In addition to melting more rapidly than loose raw materials, the briquettes are preheated and prereacted (at 212°F water is driven off, at 900°F carbon dioxide is driven off, and at 1500°F the silica starts to react) using furnace waste heat exhaust gases.

Substantial research efforts are continuously being made in an attempt to reduce furnace energy requirements. Much of the effort is directed towards the development of improved refractory material in an attempt to improve furnace fuel utilization efficiency. It is anticipated that this will be accomplished, as in the past, by increased insulation of furnaces and regenerators. Since furnace efficiencies are characteristically low, there remains a large potential for improvement in this

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(1) "Briquettes Take the Heat Off Glass", Chemical Week, Jan 11, 1978, p. 43.

area. Unfortunately, no quantitative detail on the extent to which these efforts have been successful is available in the literature.

A variety of methods for improving the energy efficiency of the glass container industry, directed primarily at the melting furnaces and annealing lehrs, are discussed in the FEA "Target" document for this industry.(1) These methods are briefly described below; the energy savings associated with them are presented in section 4.3:

Oxygen Enrichment: Enrichment of the furnace combustion air with pure oxygen can reduce the energy requirements for melting glass. Usually, the enrichment increases the oxygen in the combustion air from its normal 20.9% to up to 30% (normally 23-25%), resulting in a higher flame temperature and a reduced volume of combustion products.

Improved Combustion Control: Glass manufacturers normally utilize a long diffusion flame for purposes of controlled heat release. Excess oxygen is usually present in amounts from 2 to 5%. Application of improved oxygen sensors and monitoring equipment should permit operation at 1% excess oxygen, with commensurate fuel savings.

Higher Cullet Ratios: The energy required to make molten glass from virgin raw materials is about 30% higher than the energy to convert an equivalent weight of cullet to molten glass. For various reasons, largely environmental, a trend exists toward increased percentages of cullet usage in the container industry, with a resultant benefit in energy usage.

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(1) Battelle Columbus Laboratories, "Development and Establishment of an Energy Efficiency Improvement Target for SIC 32: Stone, Clay and Glass Products", Federal Energy Administration, June 25, 1976.

Improved Regenerator Brick: On a cyclic basis, about 50% of the heat in furnace combustion gases is extracted and then recovered by the combustion air passing through the regenerator brick (refer to Exhibit 3221-2). Recent developments in the manufacture of AZS checker refractories (alumina-zirconia-silica) for regenerators make available an energy saving opportunity, as their use permits improved regenerator efficiency. Such regenerator brick can only be brought into service when the regenerators are rebuilt, normally at the time the melting furnace is rebuilt, which is every 4 to 8 years.

All Electric Melting: Molten glass is an electrolyte and as such can be heated by its own self-resistance. Internal heating of the glass permits the construction and operation of furnaces having a thermal efficiency significantly higher than for fossil-fuel fired furnaces. Electric melting also eliminates the need for air emission control devices required for furnaces melting certain types of glass (e.g., lead silicate). Factors mitigating against the use of electric melters are the high cost of electricity and a lack of operating experience with electric melters having an output greater than 150 tons/day. A majority of glass melting furnaces are already significantly larger and replacement would require multiple electric melters for each fossil fuel-fired melter. Electric melters also have shorter campaign lives because of the higher internal temperatures which corrode the refractory linings but the higher thermal efficiency of the electric melter does result in significant energy savings.

Less than 5 percent of the glass currently melted in the U.S. is produced in electric melters; however, there has been a slow but steady trend toward their increased use during the past decade.

Electric melting of container glass is used primarily in areas of inexpensive power (e.g., TVA-Chattarooga, TN); however, its widespread use before 1980 is not technically feasible. In order for it to become a significant factor in glass container production thereafter, its cost-effectiveness must be demonstrated.

Secondary Heat Recovery: It is possible to recover additional heat not extracted by the primary regenerators through the use of various devices, including secondary/tertiary checker chambers, recuperators, heat wheels and the like. These devices permit higher air preheat temperatures and reportedly can improve fuel efficiency by as much as 10%. However, available space within existing manufacturing plants is a real problem for their installation, and plugging of these devices resulting from the buildup of particulates in the exhaust gases has been reported.

More Furnace Insulation: The use of additional insulation in conjunction with the melting furnace, especially on the furnace bottom, can result in appreciable energy savings. Such additions of insulation can only be made at the time a furnace is rebuilt and must be judiciously applied, since the temperature of the refractories in contact with the glass may be raised, thereby increasing the corrosion/solution rate of the refractory by the molten glass and leading to a shorter furnace life. However, the glass industry has continually increased their usage of furnace insulation in the past, and have the experience needed to add more insulation during furnace rebuilds.

Increased Electric Boosting: In a manner similar to electric melting, a portion of the energy added to the melting furnace can be added electrically. This has historically been done to increase the production capacity of an existing melting furnace. With this increased output brought about by electric boosting, the overall average energy per unit of output can be reduced by as much as 7 percent. The savings then do not accrue directly from fossil fuel reduction. The technology can be applied while the furnace is hot. It should be noted that a major portion of the glass industry (as much as 50 percent) already utilizes electric boosting to some extent.

More Energy Efficient Lehrs: Once formed, most glass products are heated to about 1200°F and then taken through an annealing lehr where the glass is cooled uniformly to remove residual stresses. These lehrs consume a majority of the plant energy not used in the melting furnace. Historically, lehrs have not been efficient users of energy; more recently, through the use of increased insulation and other modifications, significant energy savings have been demonstrated (averaging 70 percent). Adoption of these more efficient lehrs is primarily a matter of cost and timing: Implementation prior to 1985 could be significant.

4.3 Trends in Energy Requirements

Several of the technically feasible energy saving measures described in the previous section are, according to the FEA "Target" document for this industry, clearly economically feasible on the basis of return on investment. These are tabulated in Exhibit 3221-9, along with the associated

percent savings in energy, percent applicability to the existing glass container industry, and resulting percent total savings.

Based on the data in Exhibit 3221-9, it appears likely that the glass container industry as a whole will exhibit about a 13.6% reduction in unit energy consumption levels in 1985 relative to the present. It was shown in Exhibit 3221-8 that, at present, energy consumption per unit output averages about 11 MMBtu per ton of glass containers. Therefore, 1985 unit energy consumption will probably average around 9.6 MMBtu/ton. Based on a production level of 15.6 million tons in 1985 (section 4.1), this results in a national consumption of nearly 150 million Btu in 1985.

Since most of the energy savings are directed at fuel consumption, the percentage of energy use supplied by electricity in glass container production will probably rise slightly from its present level of 10% of input energy to perhaps 12%. The fuel used will remain primarily natural gas, with propane for short-term emergency use during curtailments and oil for those installations forced to convert from gas-firing.

By the year 2000, it is likely that the measures listed in Exhibit 3221-9 as "not economically feasible by 1985" will indeed become cost effective. If the percent of applicable production doubles by 2000, the savings from these three measures will total 6.4% relative to present levels. Assuming a doubling of applicable production for improved regenerator brick and secondary heat recovery, and an additional 20% of applicable production for improved combustion control, insulation, and improved lehrs, leads to an additional reduction of 4.7% in energy relative to present levels. The total anticipated reduction in energy usage per ton of glass between 1985-2000 is therefore 11.1% relative to present levels, or 9.6% relative to 1985 levels. This translates into a

rate of energy consumption of about 8.6 MMBtu per ton in the year 2000. Based on an annual production of 19.5 million tons in that year (section 4.1), the total national energy consumed for glass container production is estimated to reach nearly 170 million Btu. Electricity will probably account for about 20 percent of this amount, with direct-fired fuel remaining dominant at 80%. It is likely that a significant portion of the industry will have switched over to oil-firing or will be using gasified coal as furnace fuel, to the extent that natural gas is unavailable. Because of the very large investment in gas-firing equipment, however, this industry is likely to opt for paying a premium for gas rather than change fuel source. This option is, of course, a function of the elasticity of demand for glass containers, the determination of which is beyond the scope of the present study.

5.0 PLANT-SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements, including indicators of load profiles, state conditions, and reliability considerations. Several plant factors are summarized in Exhibit 3221-10.

5.1 Load Profiles

Glass container plants operate continuously, seven days a week, and shut down only when furnaces or refractories require rebuilding (once every 4 to 8 years). Hence, load factors are high (generally around 90%), with small variations on a daily or weekly basis. In recent years, however, because of widespread natural gas curtailments, some plants have been forced to curtail or shut down production activities during periods of high natural gas demand (e.g. winter months). Annual load factors, because of this constraint, have been reduced accordingly. Allowing for a 30 day shutdown for rebuilding every four to eight years, glass container plants typically operate about 350 days per year, on average.

5.2 Energy Flow Schematics

A breakdown of the energy consumed within a glass container plant, by functional area, was presented in Exhibit 3221-7 and is repeated in tabular form below:

FUNCTION	FUEL	ELECTRICITY	TOTAL
	(% of total energy)		
Batch handling	-	2	2
Melting and fining	67	3	70
Forming	-	12	12
Post Forming	8	2	10
Product Handling	1	1	2
Space Conditioning	3	1	4

Because of the relatively low efficiencies characteristic of glass furnaces, large quantities of heat are rejected to the atmosphere. Heat radiating from the furnace alone totals 3.4 MMBTU/ton of glass, while the stack gases carry away an additional 1.4 MMBTU/ton of glass, at 1000°F. The heat rejected during cooling amounts to an additional 2 MMBTU/ton.

5.3 State Conditions and Mass Flows

Representative temperatures in the glass furnace and annealing ovens have previously been reported to be 2800°F and 1200°F, respectively. On an industry-wide basis, the materials used to produce a ton of glass containers amount to the following:(1)

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(1) Gordian Associates, "The Data Base: The Potential for Energy Conservation in Nine Selected Industries", Federal Energy Administration, June 1974, p. 376.

Material	Percent of Furnace Charge	Pounds Per Ton of Glass Containers
Sand	46.4	1101
Soda Ash	15.1	358
Limestone	15.1	359
Feldspar	5.3	126
Cullet	17.4	348
Other	0.7	16
	100.0	2308

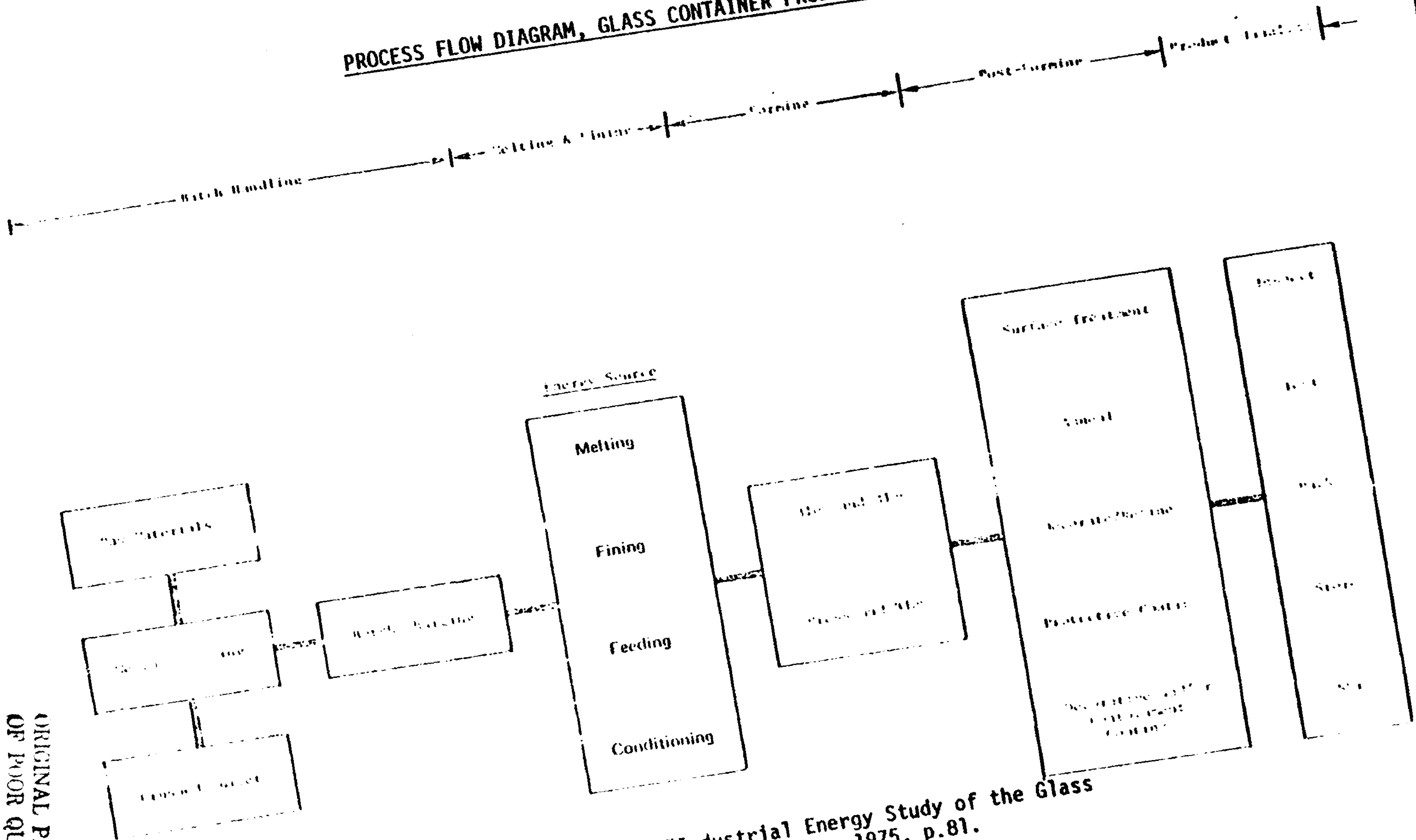
Fusion loss is typically 15.7% by weight of the raw materials charged, except that no losses occur from cullet which thus forms about 20% of the product glass.

5.4 Reliability Considerations

A reduction in power availability to a glass container plant could, in principle, be tolerated by most plants for a short duration through utilization of stand-by emergency generating equipment. Outages of extended duration, or in cases where stand-by equipment is unavailable, would necessitate shutdown procedures in the plant. Except for the resulting loss in production, and the time required to regain equilibrium, no adverse effects are foreseen for plant equipment and personnel.

EXHIBIT 3221-1

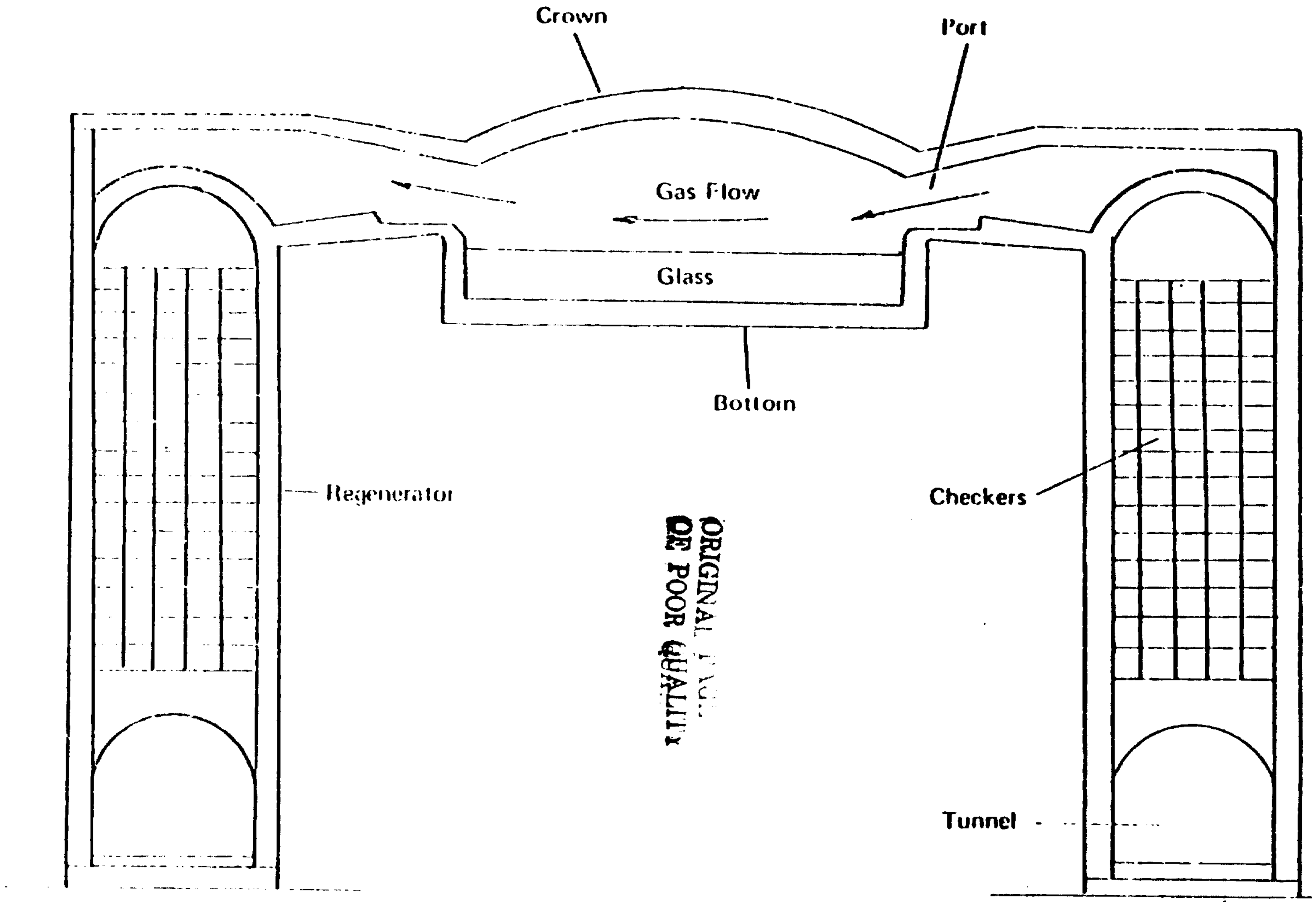
PROCESS FLOW DIAGRAM, GLASS CONTAINER PRODUCTION



Source: Battelle Columbus Laboratories, "Industrial Energy Study of the Glass Industry", Federal Energy Administration, Dec., 1975, p.81.

EXHIBIT 3221-2

CROSS SECTION OF SIDE-PORT REGENERATIVE FURNACE



Source: Battelle Columbus Laboratories, "Industrial Energy Study of the Glass Industry", Federal Energy Administration, Dec., 1975, p. 87.

EXHIBIT 3221-3

ANNUAL NATIONAL DATA (1975), GLASS CONTAINER INDUSTRY

PRODUCT PRODUCTION MILLION TONS	TOTAL ENERGY CONSUMPTION TRILLION BTU	PURCHASED ELECTRICITY TRILLION BTU	PURCHASED FUELS TRILLION BTU	COAL	OIL	GAS	OTHER	TOTAL ENERGY CONSUMPTION FOR SIC TRILLION BTU	PERCENT TOTAL ENERGY CONSUMPTION REPRESENTED
12.7	140.0	14.2*	125.8	-	24.3	101.5	-	140.0	100

* Purchased electricity converted to BTU at 3413 BTU/kWh.

EXHIBIT 3221-4

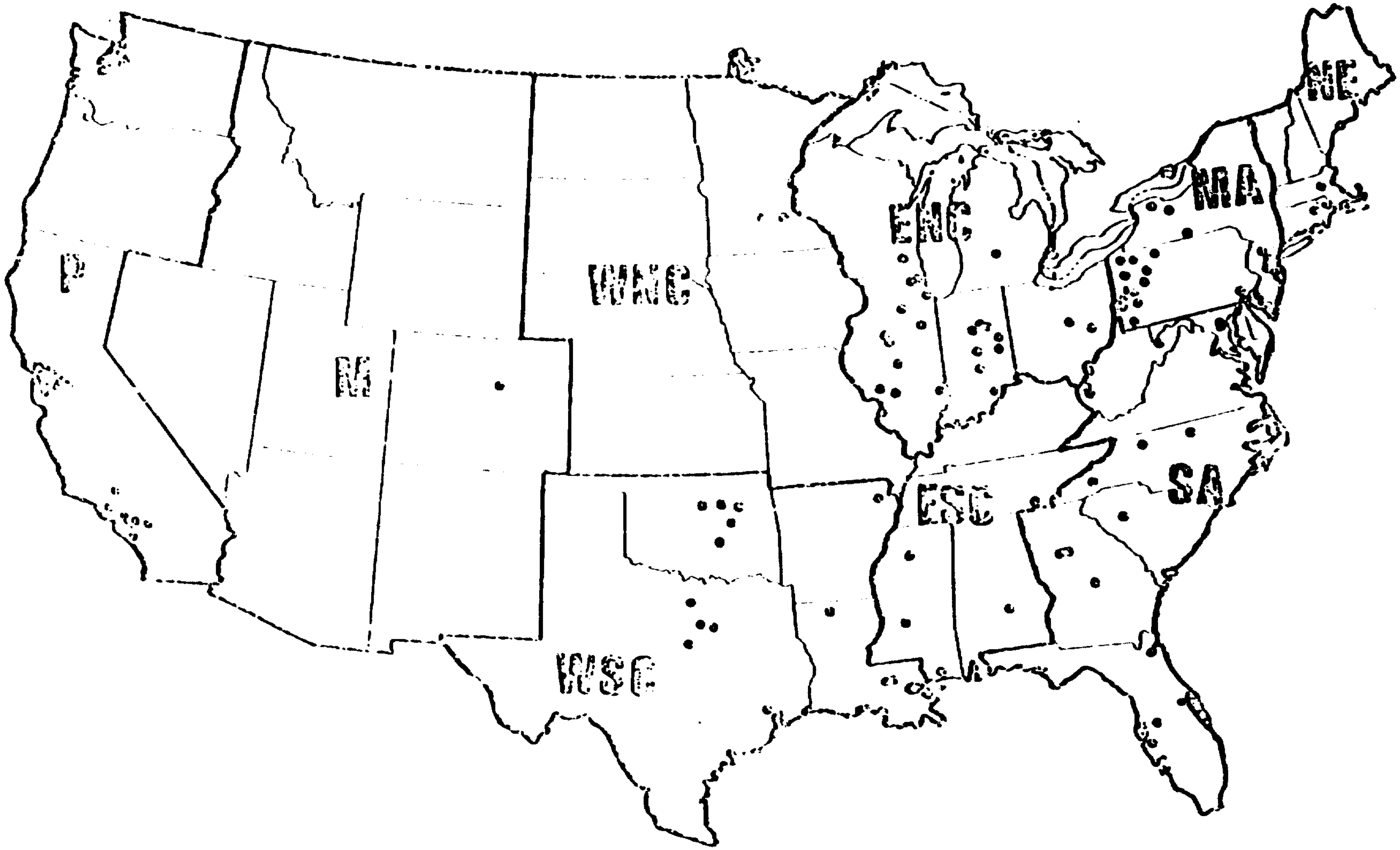
MAJOR GLASS CONTAINER MANUFACTURERS IN THE UNITED STATES

Manufacturer	Number of Plants
Anchor Hocking	9
Arkansas Glass	1
Ball Corporation	4
Brockway Glass	13
Chattanooga Glass	6
Columbine Glass	1
Diamond Glass	1
Gallo Glass	1
Glass Containers Corp.	12
Glenshaw Glass	2
Hillsboro Glass	1
Indian Head	9
Industrial Glass	1
Kerr Glass	7
Latchford Glass	1
Leone Industries	1
Liberty Glass	1
Metro Glass	4
Midland Glass	4
National Bottle Corp.	4
National Can	4
Owens-Illinois	20
Thatcher Glass	6
Underwood Glass	2
Wheaton Glass	2

Source: Battelle Columbus Laboratories, "Industrial Energy Study of the Glass Industry", Federal Energy Administration, Dec., 1975, p.82.

EXHIBIT 3221-5

REGIONAL DISTRIBUTION OF GLASS CONTAINER MANUFACTURERS IN THE UNITED STATES



Source: Battelle Columbus Laboratories, "Industrial Energy Study of the Glass Industry", Federal Energy Administration, Dec. 1975, p.84.

EXHIBIT 3221-6

RANGE OF ENERGY USAGE BY PROCESS STEP

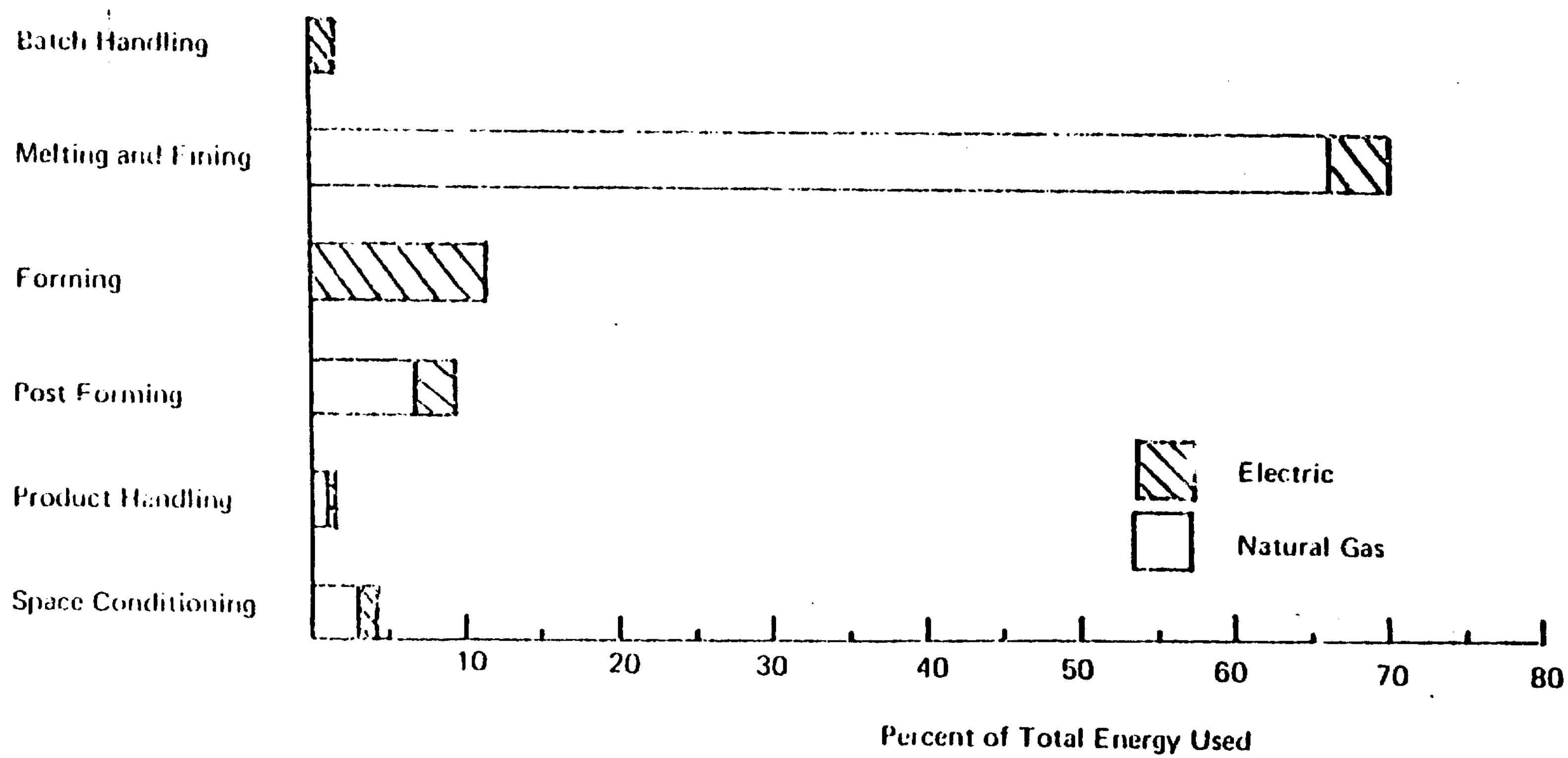
(PERCENT)

	MINIMUM	MAXIMUM	NOMINAL
Batch handling	0.5	4.0	2.0
Melting	60.0	82.0	70.0
Forming	7.0	18.0	11.5
Post Forming	6.0	12.0	9.5
Product Handling	1.0	5.0	2.5
Space Conditioning	2.0		4.5
			100.0

Source: Battelle Columbus Laboratories, "Industrial Energy Study of the Glass Industry", FEA, Dec., 1975, p. 100.

EXHIBIT 3221-7

ENERGY DISTRIBUTION IN A GLASS CONTAINER PLANT USING ONLY NATURAL GAS AND ELECTRICITY



Source: Battelle Columbus Laboratories, "Industrial Energy Study of the Glass Industry, Federal Energy Administration, Dec. 1975, p. 101

EXHIBIT 3221-8

ENERGY CONSUMPTION PER UNIT OUTPUT* IN GLASS CONTAINER PRODUCTION

Electricity Million Btu Per Ton	Hot Water Million Btu Per Ton	Steam (Million Btu/Ton)			Direct Fuel*** Million Btu Per Ton	Exhaust Stream	
		To 300°F	300-500°F	Over 500°F		Temperature °F	Energy Million Btu Per Ton
1.12*	-	-	-	-	9.90	1000	1.4

* Assuming 3413 Btu/kWh

EXHIBIT 3221-9

ECONOMICALLY FEASIBLE ENERGY SAVING MEASURES IN GLASS CONTAINER PRODUCTION

Measure	Percent Energy Reduction Per Unit of Production	Percent of Production Applicable by 1985	Total Percent Savings by 1985
Improved Combustion Control	2.2	60	1.3
Increased Cullet Ratio	2.3	100	2.3
Improved Regenerator Brick	2.5	8	0.2
Secondary Heat Recovery	6.4	25	1.6
More Furnace Insulation	6.3	60	3.8
More Energy Efficient Lehrs	6.0	60	3.6
Housekeeping Measures	0.8	100	0.8
Total	-	-	13.6
MEASURES NOT ECONOMICALLY FEASIBLE BY 1985:			
Oxygen Enrichment	6.0	10	0.6
All Electric Melting	27.5	8	2.2
Increased Electric Boosting	8.0	5	0.4
Total			3.2

Data Based on: Battelle Columbus Laboratories, "Development and Establishment of an Energy Efficiency Improvement target for SIC 32: Stone, Clay, ad Glass Products," Federal Energy Administration, June 25, 1976.

EXHIBIT 3221-10

GLASS CONTAINER PLANT FACTORS

TYPICAL PLANT CAPACITY TONS/YEAR	PLANT SIZE RANGE TONS/YEAR	ELECTRIC LOAD FACTOR	THERMAL ELECTRICAL COINCIDENCE FACTOR	PROJECTED APPLICABILITY TO 2000
125,000	35,000-350,000	0.90	1.0	*

* Due to the relatively slow growth anticipated for this industry, new plants coming on-stream are not likely to be significantly larger than existing facilities. Furthermore, to the extent that new facilities incorporate electric melting, they are likely to be smaller that present "typical" sizes.

CEMENT PRODUCTION

1.0 PROCESS IDENTIFICATION

This section identifies and specifically defines the industry, and provides a brief description of the current production processes employed.

1.1 SIC Classification

The production of cement is classified under SIC code 3241 which covers companies "primarily engaged in manufacturing hydraulic cement, including portland, natural, masonry and pozzolan cements." Other products of many cement companies, such as lime, are included within their own SIC code classifications. The most widely used portland cement is the normal "Type I" cement, although other types offering special properties, such as high early strength or sulfate resistance, are also available.

1.2 Basic Process Description

The production sequence for the manufacture of portland cement can be divided into the following activities:

- acquiring raw materials
- preparing raw materials
- producing clinker
- grinding and mixing product cement

There are two common processing sequences based on these steps, the wet and dry process. In the dry process, raw materials are ground and blended dry. In the wet process these operations are carried out using a slurry of the materials in water. In other respects the processes are essentially the same. There are also variations of the basic process

such as semiwet or semidry systems, in which raw materials are fed into the kiln in the form of nodules or pellets. These processes, however, are generally less common than the wet or dry process. The basic wet and dry processes used to make cement are shown diagramatically in Exhibit 3241-1.

Raw material acquisition. The raw materials for all types of portland cement are similar, but proportions of the materials used vary according to the desired end product. These variations, the final product blending procedures, and the use of additives or admixtures in the product, allow a wide range of cements to be marketed, each with its own characteristics for specific applications.

The raw materials for cement manufacture must provide compounds containing lime, silica, and alumina in suitable proportions. Natural calcareous deposits, such as limestone and shell beds, provide lime. Natural argillaceous deposits, such as clay, shale, and slate deposits, supply both silica and alumina. Natural deposits of argillaceous limestone or of marl (a calcareous clay) can provide all three basic ingredients, although not necessarily in the desired proportions. Raw materials must therefore be blended in the appropriate quantities to provide a carefully controlled composition for the feed to the cement kiln. Where raw materials are particularly variable, blending should in fact start at the quarry, with selective quarrying based on a thorough geological survey and regular analyses of the rock. A blending stockpile of crushed stone is often used to even out short-term variations in quality.

Preparation of raw materials. After the raw materials are transported from quarries to the cement plant, they are crushed and ground to produce fine-particle-size materials for feeding to the kiln.

The choice of a size-reduction process is governed primarily by the characteristics of the raw materials and by moisture content in particular. If raw materials have a naturally high water content, the wet process is generally used. During the grinding, water is added to produce a thin mud, or slurry. The slurry, typically containing over 30% water, is mixed and blended in storage tanks until it is processed in the kiln.

In the dry process, the desired proportions of the raw material are fed to grinding mills without the addition of water; indeed, the raw materials are frequently dried during the grinding process by hot waste gases from the kiln or by auxiliary burners.

Energy consumption in grinding by the wet process is usually reported as being lower than that by the dry process. In fact, wet-process raw materials are generally softer and require less energy to grind but, when wet and dry processes use the same raw materials, grinding energy is found to be about the same for each system. Homogenization of wet slurry is considered somewhat easier than homogenization of dry powder. However, dry-process raw materials can be homogenized with few problems if this part of the operation is performed carefully. The effective blending of raw materials to minimize kiln feed composition changes is particularly important for the smooth operation of suspension preheater kilns.

The use of roller mills for grinding raw materials has increased progressively in recent years, particularly in Europe and Japan. One reason for this is the suitability of roller mills for operating in conjunction with suspension preheater kilns. Hot kiln waste gases are passed through the roller mill to dry the raw materials during grinding.

Roller mills usually use less energy for grinding than conventional ball mills, especially for hard limestones, which are amenable to size reduction by rolling action. By contrast, however, some sticky materials do not lend themselves so readily to grinding in roller mills.

Clinker production. The key process in making cement is the "burning" of the raw materials in a rotary kiln. The kiln is a long, cylindrical brick-lined furnace, mounted at a slight incline to the horizontal, which rotates slowly on its axis. Present day commercial kilns vary from about 300 to well over 650 feet in length and are about 10 to 25 feet in diameter at the sintering zone. So-called shaft kilns, which are mounted vertically and do not rotate, typically are not being installed today.

The processed materials finally leave the kiln at the lower end as clinker, rough textured lumps or pellets ranging from about 0.1 to 2 inches in diameter. The outgoing clinker is cooled, the heat which is removed normally being used to preheat incoming combustion air. A number of different clinker coolers are commercially available. Some are based on moving grate systems; others consist of tubes mounted externally along the kiln periphery near the clinker outlet ("planetary" coolers). Clinker falls into these tubes and tumbles along them toward the outlet. Air, normally introduced into the tubes by induced draft, is preheated before being used in the combustion of kiln fuel.

Grinding and mixing of product cement. The final stage of manufacture consists of grinding the lumps of clinker to a fine powder. The clinker, which is extremely hard, is ground together with a small amount of gypsum (calcium sulfate); approximately 3 to 5% by weight is added. The gypsum is used to control the time required for the cement to set when it is mixed with water to make concrete.

1.3 Preheaters

Many modern kilns are preceeded by a preheater system in which hot exit gases give up heat to the cold incoming raw meal. A number of different preheater systems are commercially available; manufacturers such as F.L. Smidth (Denmark), Polysius (Germany), Miag (Germany), Humboldt-Wedag (Germany), and F.L.C. (France) have built hundreds of preheater plants throughout the world. Contractors offering preheaters in the US also include Fuller and Allis Chalmers, whose process technology is derived principally from Humboldt and Miag respectively.

One type of preheater concept is found in the semiwet and semidry processes. The semidry process, in which nodules are formed by adding water to the dry raw mix, is more frequently used. In the semiwet process, the slurry of raw materials is dewatered in mechanical filter presses to about 20 to 22% moisture, and the filter cakes are then formed into nodules. In both processes the nodules are dried on a moving grate preheater through which the hot exit gases are passed. The Lepol kiln is one example of the semidry system.

Suspension-preheater systems are found in many modern dry-process plants. The suspension preheaters consist of several stages of cyclones built on top of the other (Exhibit 3241-2). Typically four stages are used. The cold incoming raw meal is intimately contacted with the hot exit gases in the cyclones and gradually drops down through the system to the inlet end of the kiln, at which point it is 40 to 50% calcined. Typical moisture content of the raw meal entering a four-stage preheater system is about 0.5 to 1%. It is important that the exit gases leave at a sufficiently high temperature to ensure rapid removal of moisture from the raw meal, thus reducing the risk of solids clogging the preheater

pipework. Recent modifications to the suspension preheater system include German and Japanese "precalcining" designs with two stages of firing. In the Humboldt-Wedag Pyroclon design, for example, a burner is placed at the bottom of a vertical shaft incorporated into the preheater system. This burns about two-thirds of the fuel used in the plant, the other one-third being burned in the conventional manner in the kiln itself. The feed is about 90% calcined before it enters the rotating kiln. Recent Japanese designs use auxiliary firing within a cyclone vessel of the preheater system (a "flash furnace"), which ensures intimate mixing between raw materials and burner gases (Exhibit 3241-2). The multistage firing systems allow shorter kilns to be used, and cement production per unit volume of the kiln is increased to about three times that of the conventional cement kiln. Capital investment savings and reduced maintenance are claimed for plants rated at over 3000 tons/day, but energy consumption is apparently not significantly different from that of conventional preheater kilns.

1.4 The Alkali Problem

Although preheater systems improve fuel economy, they do have the disadvantage that such impurities as alkali metal compounds, which would normally be removed from the plant in the hot exit gases, can be condensed on the cold raw meal and reintroduced to the kiln. In the kiln they are again vaporized and swept back to the preheater. Thus a cycle may be set up between the preheater and the kiln, and alkali metals can build up significantly. Plugging in the preheater may be a serious problem when this occurs. Eventually equilibrium is reached, with relatively

large quantities of alkali being removed in the clinker. This can cause problems in concrete because of the so-called alkali-aggregate reaction: compounds in certain aggregates react slowly with the alkalis to produce severe cracking in concrete structures. For this reason, most US cement is specified as "low alkali" (less than 0.6 wt. % alkali metals expressed as Na_2O).

The potential for the alkali-aggregate reaction is, however, a local phenomenon. About 10% of all US aggregates may be reactive, and these are concentrated in specific geographic areas. But because of the difficulty of segregating low-and high-alkali cements, as well as the potential problem of alkali reactivity, it has become common practice in many areas of the United States for <u>all</u> cement to conform to a low-alkali specification. The alkali-aggregate-reaction problem is not experienced to any significant extent in Europe, except in a few small areas of Northern Germany (and perhaps in parts of the UK, according to recent evidence).

The suspension-preheater design may require the inclusion of a gas bypass system to avoid problems of alkali buildup in the cement kiln. If the alkali content of clinker rises too high, about 10% of the kiln gas is typically bypassed and some of the alkali components in the vapor phase are removed with this gas. Cooling the gas by direct water injection for example, from 1100 to 450°C (2000 to 850°F) causes condensation of the contaminants. The gas can then be used to dry raw materials with no risk of alkali buildup. As a general rule, bypassing 10% of the gas represents an extra heat consumption on the order of 60 kcal/kg of clinker (say 0.2 MMBtu/ton of cement).

Unfortunately, effective removal of alkali may require preheater bypassing substantially in excess of 10% for some raw materials (Exhibit 3241-4). Thus for example, for a 20% bypass situation, a loss of 120 kcal/kg (0.43 MMBtu/ton) can be expected; this represents about half the potential energy improvement of a suspension-preheater kiln over a well operated long dry kiln.

In addition to alkali removal, bypassing also leads to increasing loss of dust from the kiln system. This represents a further loss in energy efficiency per ton of product clinker.

Interestingly, a similar type of cycling problem can be observed with chlorides in preheater kilns, again requiring the use of a bypass to control buildup.

In connection with alkali cycles, it should be noted that the level of sulfur in the system is an important factor. When constant amounts of alkalis and sulfur are introduced into the kiln, a balanced situation can be set up in which sodium and potassium sulfates are formed and removed in the clinker. This poses few problems if the amount of alkali is not excessive. When fluctuation in the relative amounts of alkalis and sulfur occurs, however, serious preheater plugging can be caused by the formation of excessive amounts of calcium sulfate or by the vaporization and subsequent condensation of alkali oxides. In practice, a perfect balance is impossible to maintain because of raw-material variations and changes in the quantity of sulfur in fuels. Variations in fuel sulfur content are particularly important where kilns are fired with coal.

Many of the earliest suspension preheater kilns erected in the US suffered from a lack of understanding of the raw material chemistry and

the influence of sulfur in the fuel on the all-important alkali-sulfur balance. Problems of preheater plugging were therefore often extremely serious, and indeed some systems were deemed "inoperable" and were shut down.

It is important to note that relaxing the alkali specification for cements, or at least applying it judiciously only to those situations where reactive aggregates are expected, could lead to greater benefits in improved energy efficiency than might otherwise be the case from the use of preheater kilns in the US cement industry.

It should also be mentioned that certain pozzolanic materials, such as fly ash, appear to have an inhibiting effect on the alkali reaction. Using pozzolans in blended cements at reasonably high levels (e.g., 20 to 30%) may solve part of the alkali problem and thus allow greater use to be made of the energy-saving potential of suspension preheater technology.

2.0 NATIONAL DATA

This section includes data on the structure of the US industry, capacity and plant location data, and energy consumption figures for the industry. The data is based primarily on information furnished by the Portland Cement Association, whose regular energy survey covers over 99 percent of the industry manufacturing capacity, and is summarized in Exhibit 3241-5.

2.1 Capacity and Production Data

Total US cement manufacturing capacity (including gray and white plants, and plants with grinding facilities only) was 95 million tons per year, as of December 31, 1976[1]. Cement consumption in 1976 was a little over 70 million tons, with 1977 and 1978 consumption expected to rise above 75 million tons per year for the first time since 1974:

U.S. CEMENT CONSUMPTION BY REGION
(1,000 Tons)

Region	1972	1973	1974	1975	1976	Forecast 1977	Forecast 1978	Percent Change 78/77
Eastern	16,728	18,015	15,059	12,687	12,161	12,335	12,770	+3.5
Great Lakes-Midwestern	14,714	16,009	14,317	12,420	13,454	14,135	14,510	+2.7
Southeastern	14,088	15,387	13,373	10,142	10,776	11,790	12,300	+4.3
North Central	4,790	5,379	5,255	4,787	5,217	5,360	5,310	-0.9
Rocky Mountain-Northwest	5,390	5,728	5,533	5,161	5,285	6,390	6,365	-0.4
Pacific Southwest	10,839	11,239	10,038	8,747	9,123	10,370	10,515	+1.4
South Central	14,226	14,443	13,942	13,031	14,082	15,120	15,150	+0.2
Total	80,775	86,200	79,027	67,025	70,599	75,500	76,920	+1.9

SOURCE: PCA Economic Research Department, "US Cement Consumption Forecast, October, 1977".

(1) Economic Research Department, Portland Cement Association, Skokie, Illinois "U.S. Portland Cement Industry: Plant Information Summary", December 31, 1976

Cement is a product with a relatively low value-to-weight ratio. Cement plants therefore tend to be located within 150 to 200 miles of their principal markets because transportation costs are normally a significant factor in the total cost picture. Road transportation costs are relatively high, although where access to less costly water transportation is available, market areas can be expanded considerably.

Distribution costs, population density, and raw material availability have therefore all played a part in the development of the US industry. In 1976, there were over 50 companies producing cement in over 380 kilns in 172 plants. No single company is dominant in the industry. In 1976, the largest company was Ideal Cement, with 6.7 percent of industry capacity, and 50 percent of industry capacity was represented by the top eleven companies (Exhibit 3241-6). The geographical distribution of cement plants is shown in Exhibit 3241-7, and a summary of plant capacities by state in Exhibit 3241-8.

With respect to kiln sizes, Exhibit 3241-9 presents data on kiln size, broken down according to wet and dry process and by age. The average kiln capacity is about 233,000 tons of clinker per year and wet process capacity represents about 55% of the total. A detailed survey of plant and kiln sizes was performed by the Polysius Corporation[(1)] and this indicated that 9 percent of plants (20 percent of capacity) have an output over 3000 tons per day. About 86% of kilns are rated at 1000 tons per day or less (68 percent of industry capacity) and 7 percent are rated over 2000 tons per day (18 percent of capacity). This can be compared with Germany, for example, where 22 percent of kilns are larger than 2000 tons per day (31 percent of capacity). This data, of course,

(1) Gerd A. Shroth, Polysius Corporation, presented at the FEA-PCA Seminar on Energy Management in the Cement Industry, Philadelphia, October 21-22, 1975.

refers to the situation about four years ago, and there is already evident a clear trend to much larger kilns. Exhibit 3241-10 presents the average size of new kilns commissioned in the US since 1905. A typical modern preheater kiln will be designed with a clinker capacity in the range of 500,000 to 1,000,000 tons per year. It is particularly important to note the age of kilns, as reported in Exhibit 3241-9: the US industry operates a large number of very old plants.

The range of existing plant sizes is quite broad. The Portland Cement Association "Plant Information Summary" indicates that the smallest plant operating in 1976 had an annual capacity of 170,000 tons of cement and the largest 2,322,000 tons.

2.2 <u>Annual Energy Consumption Data</u>

The most recent energy data reported by the Portland Cement Association in September 1977 was drawn from a survey which covered 99.2 percent of industry capacity. For the purpose of reporting the data in a standardized manner, energy usage is expressed in terms of "equivalent tons of production", a method that has been used by the PCA for several years. This is done because clinker production is not necessarily related directly to finished cement production. Equivalent tons are calculated on the basis of 92 percent of reported clinker production plus 8 percent of reported cement production. The basic data for the period 1972 to mid-1977 are presented in Exhibit 3241-11, with a breakdown by energy type in Exhibit 3241-12.

Exhibit 3241-11 shows that, for the first half of 1977, energy consumption amounted to 6.27 million Btu per ton of production. This was 7.1 percent less than the usage in 1972, the base year for the current industrial energy efficiency improvement program administered by the US Department

of Energy. In fact, allowing for increased electric power consumption attributable to the operation of pollution control and coal-handling equipment, cement industry energy efficiency was 7.7 percent improved in the first half of 1977 compared to 1972.

Exhibit 3241-12 shows that the industry has increased its use of coal and coke from 36 percent of total energy consumption to 57 percent. Natural gas consumption has been reduced by almost half, while petroleum usage has remained about the same.

3.0 PROCESS ENERGY REQUIREMENTS

Energy consumption in a cement plant consists primarily of fuel used in firing the kiln and electricity to drive crushing and grinding equipment (for raw material preparation and grinding of the product) and to rotate the kiln itself. The energy requirements per ton of cement are summarized in Exhibit 3241-13.

3.1 Unit Energy Consumption Data

In terms of energy efficiency as measured by fuel burned in the kiln, there are significant differences among the processes described previously in Section 1.1. The kiln fuel consumption of a cement plant is a function of parameters such as age and size of the plant, characteristics of the raw materials, steadiness of operation, and operator experience, all of which are peculiar to a particular plant. On the basis of "best practice/modern large plants," however, it is possible to generalize fuel consumption by process category:

REPRESENTATIVE FUEL CONSUMPTION

Process	Kiln Fuel, MMBtu/ton Cement
Dry (long kiln)	3.1
Wet (long kiln)	4.7
Semidry (grate preheater, Lepol type)	3.1
Dry (suspension preheater)	2.7

Of course, these figures are considerably lower than the industry-wide consumption figure of about 5.8 million btu per ton quoted in the most recent PCA Energy Report (allowing 0.5 MMBtu* for electricity consumption). The most important single reason for this is the fact that the average age of US kilns is almost 20 years; about 17 percent of kilns were built prior to 1930. As Exhibit 3241-9 shows, there is a high proportion of old

* at 3413 Btu/kWh

wet kilns, most of which are small in size, and this leads to a high fuel consumption for the industry as a whole.

With respect to electricity use, a typical figure for US plants would be about 145 kWh per ton of cement production, broken down as follows:(1)

Raw-material grinding	37
Clinker grinding	55
Subtotal	92
Kiln department power	29
Quarry use	6
Drying of raw materials	2
Miscellaneous (including lighting)	16
Subtotal	53
Grand Total	145

Wide variations in electrical energy use are possible. For example, the use of roller mills for raw material grinding may save say 10% of the energy used in conventional ball mills. Differences in the fineness of the final product can account for differences of perhaps 20 kWh per ton for grinding. Differences in electrical energy use for raw mix homogenizing and mechanical conveying may account for differences of 5 to 10 kWh per ton. Finally, the type of clinker cooler used in a cement plant will influence electricity consumption:

TYPICAL COOLER PERFORMANCE DATA

Cooler type	Electricity consumption, kWh/ton of clinker	Efficiency with wet process, %	Efficiency with dry process %
Planetary	0.5-1.4	67	73
Shaft	5-8	-	80
Grate	4-8	58	77

(1) Gordian Associates Inc., "The Cement Industry", NATO/CCMS Report No. 46, 1976, page 11.

As described previously, it may sometimes be necessary to employ an exhaust gas bypass on a suspension preheater kiln in order to control alkali content in the cement product. For the bypassing of 25 percent of the exhaust gas, a representative figure, an energy penalty of about 0.5-0.6 million btu per ton of cement would be paid.

A detailed summary of energy consumption data is presented in Exhibit 3241-14.

3.2 Details of Electricity Consumption

Cement plants operate continuously, 24 hours a day, generally with annual load factors in the region of 90 percent (except where modified by local market factors). A breakdown of electrical energy use is given in Section 3.1: from this, it may be seen that there exists the possibility for modifying the plant daily load curve by scheduling certain raw material and product grinding operations to off peak hours, assuming adequate storage is available for the materials. The kiln itself must be kept operating steadily at all times. In general, however, it may be considered that the production of cement requires a steady, reliable source of electrical power on a 24-hour per day basis.

3.3 Details of Thermal Energy Consumption

Apart from the direct firing of fuel in the kiln, essentially no other thermal energy is consumed. Most drivers in a cement plant are electrically driven, although in principle it might be possible for steam drivers to be substituted. The fuel itself can be coal, oil-derived or natural gas, or any combination. Other fuels which are sometimes used include petroleum coke, lignite, charcoal, and petroleum refinery gases. The fuel serves to maintain a temperature in the clinkering zone of the kiln in the region of 2900°F. Air for combustion is usually preheated by extracting heat from the clinker cooler, and exit gases

leaving the feed end of the kiln may be used to preheat incoming cold feed or to dry moist raw materials in the grinding mills. Through integrated heat recovery systems, the overall fuel consumed in the kiln may thus be reduced substantially in a modern well-designed plant.

4.0 ANTICIPATED TRENDS

This section discusses the trends likely to occur in the cement industry through the year 2000, with emphasis on production, process technology and energy consumption.

4.1 Product Growth Trends

As noted earlier, the annual production of cement is rising from the depressed levels of 1975-1976: annual production in the short-term future is expected to be in the range of 75 to 80 million tons. The long term growth rate for cement consumption is approximately 2 per cent per year, suggesting an annual level of production by 1985 of about 90 million tons and between 115 and 120 million tons in the year 2000.

A number of factors affect the use of cement, the single most important of which is the state of the construction industry. In the construction of commercial buildings in particular, cement faces competition from other load-bearing materials such as brick and steel. Many factors must be considered in choosing a construction material. Among these are:

Fire protection
Durability
Maintenance
Potential weight of the structure
Space required for load-bearing components
Acoustical properties
Thermal properties

Concrete compares favorably with most other materials with regard to the first three considerations but does have disadvantages in the next two. The acoustical properties of a building will normally be modified significantly by the internal finish of rooms.

The advantageous thermal properties of massive concrete structural

elements have perhaps been underutilized in the past. The fact that massive concrete buildings are able to store significant amounts of heat may allow substantial operating energy savings if this characteristic is properly exploited at the design stage. For example, during the winter the heat-storage properties of concrete can be used to maintain inside temperature levels during the day by heating up the concrete using off-peak electrical heating during the night. In addition, the massive concrete structure can be used to store as much solar-derived heat as possible. During the summer the reverse situation exists. The massive structure can be cooled with off-peak electricity used to run air-conditioning systems and can also take advantage of natural overnight cooling.

With respect to the energy input to various construction materials, cement is energy-intensive but concrete is considerably less so. Clearly, the comparison of energy input should be based as far as possible on equivalent duties for competing materials. A direct comparison of 1 meter high steel, cement, and brick columns capable of carrying a 1000-ton load indicates the following:

RELATIVE ENERGY CONTENTS	
Steel	100
Brick	65
Concrete	16

Other comparisons, including a study of beams with different loadings and span widths, show that concrete beams required significantly less energy input in all cases.

Thus it appears that concrete offers a potential for savings in the energy investment in construction and has favorable thermal properties

that can be exploited through the proper design of buildings. These factors should guarantee that the long-term growth in cement consumption is at least maintained at historical levels.

4.2 Process Changes

For over a century, cement has been made in long rotating kilns by essentially the same process. Two basic versions exist, the wet and dry process. Over the last twenty-five years, however, two new modifications to the traditional process have become increasingly popular. These were the introduction of the suspension preheater concept in the early 1950's and of the flash calciner in the early 1970's (see Section 1.3).

The history of preheater plants has been somewhat checkered in the U.S. since the installation of the first plant in the early 1950's. The first U.S. plant at Evansville (National Gypsum) used Humboldt technology and was the fourth in the world, following three similar plants in Germany. Indeed, the initial U.S. plants were constructed about the same time as the first European plants but, for reasons which are discussed further below, many of them proved unsuccessful under U.S. conditions and the technology rapidly fell out of favor. By contrast, hundreds of SP plants were then built throughout the world. The high fuel efficiency of the SP system is a major factor in their acceptance by the international cement industry, and it must be recalled that U.S. energy prices have historically been lower than in most nations. Problems with alkalis and kerogens in the first generation of SP plants in the U.S. were therefore enough to dissuade all but two domestic manufacturers from buying the new technology from 1955 to 1970*.

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* H.M. Garrett, "The Potential Promise - Prospects and Pitfalls in Energy Conservation by the U.S. Cement Industry", FEA-PCA Seminar, Philadelphia, October 1975.

The problems encountered by the first SP plants in the U.S. can be attributed primarily to alkalis and kerogens in the raw materials. The kerogens, or combustibles, led to severe problems in the plants of Ideal (Fort Collins) and Huron (Alpina). With combustibles in the raw materials, there is always the risk of premature combustion within the preheater tower, with potentially serious damage to the cyclones resulting. Kerogens are naturally occuring materials, but even the use of fly ash in the raw material can lead to preignition of a similar nature. This apparently occurs at the recently commissioned Florida Mining Brooksville Plant, and requires particular attention by the operators.

The problem of alkalis is a good deal more complex. The volatization and condensation of alkalis has been discussed previously in this report and it is obvious that alkali condensation in preheater piping may rapidly lead to plugging of the whole feed system. It was an inadequate appreciation of the chemistry of the raw materials which led to severe plugging problems in the first U.S. preheater plants. As is now well known, it is primarily the balance between alkalis and sulfur which requires careful attention in order to operate SP systems successfully. This means that the quality of coal must be monitored especially carefully when used to fire a suspension preheater kiln.

Increasing fuel costs in the U.S. subsequently led to a resurgence of interest in preheater technology. The next series of plants, which may be called "second generation" systems, were commissioned in the early 1970's and have proved more successful. However, some plants did experience significant problems, not all of which can be attributed to the preheater technology itself, while others were relatively successful.

Overall, confidence in the SP technology could not be deemed totally enthusiastic; R. MacLean, President of the PCA, testified to the FEA in December 1976 that about two years was a reasonable estimate of the time required to debug a typical new SP plant after the initial start-up.

The learning experience of the designers, contractors and plant operators now appears to have reached the stage where confidence has largely been restored. Over 25 SP plants from 1975 to date have been built or ordered in the U.S., and in fact no new wet or dry kilns have been erected in that period These "third generation" plants, which include precalciner designs, incorporate the latest technology for raw meal homogenizing and exit gas bypassing. With the improved technology now available, and with proper attention to operator training, there is every reason to believe that the two year start up period is a thing of the past, and a new SP kiln can be brought on-line within a more reasonable two to three month period. A list of US preheater kiln installations is given as Exhibit 3241-15.

The apparent acceptance of the suspension preheater concept, and that of flash calcining also, should lead to a steady decrease in the amount of kiln fuel consumed in the manufacture of cement by the industry as a whole. It is reasonable to assume that the industry average will steadily approach the fuel efficiency of 2.7 to 3.0 million btu per ton achieved in most large modern SP plants.

With respect to electricity use, there appears to be little prospect of major changes being observed. Since a significant amount of electrical energy is consumed in grinding clinker, it is possible that a reduction in the degree of fineness required by final product specifications will contribute to a reduction in electricity use. Other factors will

undoubtedly include the more widespread use of roller mills for raw material grinding. By the year 2000, it is reasonable to expect the US industry to have reduced electricity consumption from 145 kWh per ton to a level much closer to that currently consumed in Europe, that is, about 100 to 110 kWh per ton. Note, however, that any move to impose stricter environmental standards on cement plants will have an adverse effect on electricity consumption; already about 7 kWh per ton is consumed in the operation of pollution control equipment to meet stringent US emission standards.

4.3 Implementation of New Technology

Although a fluid-bed process for cement manufacutre has been developed, no significant change in the technology used in the industry is believed to be likely through 2000. To date, no major plant using the fluid bed technique, or any other novel technology, has been demonstrated. In terms of the industry as a whole, it appears likely that the suspension preheater and flash calciner will be the dominant processes in use in all major facilities.

4.4 Trends in Energy Requirements

As noted earlier, the US industry is expected to continue to modernize through the construction of energy-efficient SP and flash calciner systems, continuing a steady trend towards the use of less fuel in the kiln. By 2000, we would expect the overall industry average energy consumption (including electricity) to be about 3.5 million btu per ton of cement.

In addition to the move toward more efficient plants, it is interesting to note the potential for utilizing "blended cements" in the construction industry. Currently, blended cements are made from portland cement

clinker interground with "waste" materials such as fly ash and slags. While this may represent a major potential for energy savings in construction (because the fly ash and slag can be considered to contain zero energy), there will be no direct effect on specific energy consumption at the cement plant. Nevertheless, it is possible that widespread adoption of blended cements could lead to a relatively slow rate of growth of cement plant capacity, and an increasing market share being taken by the blended materials. The rate of growth of the total energy consumption for the cement industry could therefore be reduced proportionately.

With respect to the type of fuel used by the cement industry, there is a strong trend already apparent towards the use of coal. We would anticipate that the fuel mix for the industry will continue to favor the use of coal, to such an extent that kiln fuel might be almost totally dependent on coal by the year 2000:

	Estimated Fuel Use, %
Coal	94
Natural Gas	2
Oil	4
	100

Note, however, that plants will continue to utilize the most economical combination of available fuels to minimize energy costs, and therefore the above mix will in fact be dependent on relative fuel costs. Cement plants may also burn waste materials, such as shredded municipal refuse and spent lubricating oils, to levels perhaps over twenty percent of fuel intake for specific plants. However, on an industry-wide basis, waste materials are not believed likely to exceed five percent of total fuel consumption, with the balance of fossil fuels divided in the proportions indicated above.

5.0 PLANT SPECIFIC DATA

This section provides additional data relating to specific plant energy requirements, including indications of load profiles, state conditions and reliability considerations. A number of these key factors are presented in Exhibit 3241-16.

5.1 Load Profiles

The continuous operating nature of a cement plant means that a steady and reliable electrical supply is generally required. However, there are some operations which can be scheduled for off-peak hours, where equipment capacity, storage capacity and an economic incentive exist. For example, final product grinding, consuming about one third of the total plant electrical demand (55 out of 145 kWh per ton) could be carried out on a two-shift basis to take advantage of off-peak electrical rates. The capacity of the grinding mills must be sufficient to allow 24 hours clinker production to be processed in 16 hours, and there should be adequate storage for clinker during the eight hours that the mills are shut down. It is therefore possible for a cement plant to "manipulate" the electrical load profile in a number of ways to minimize power costs, in accordance with the specific plant electricity rate schedule.

5.2 Energy Flow Schematics

The energy consumed in a cement plant consists of electricity and some form of directly-fired fuel. There is, for all practical purposes, no steam or other form of thermal energy used in the manufacture of cement. In view of the straigntforward nature of cement plant energy systems, no diagram is provided.

C9

5.3 State Conditions and Mass Flows

Representative temperatures around a cement kiln are shown in Exhibit 3241-17. On an industry-wide basis, the materials used to produce a ton of clinker amount to the following:

Raw materials used per ton of clinker

		tons
Calcereous	Limestone	1.12
	Cement rock and shells	0.36
Argillaceous	Clay	0.10
	Shale and other	0.06
Siliceous	Sand	0.03
	Sandstone and quartz	0.01
Ferrous	Iron ore, pyrites, etc.	0.01
All other		0.07
		1.76

(Source: Bureau of Mines data for 1974).

5.4 Reliability Considerations

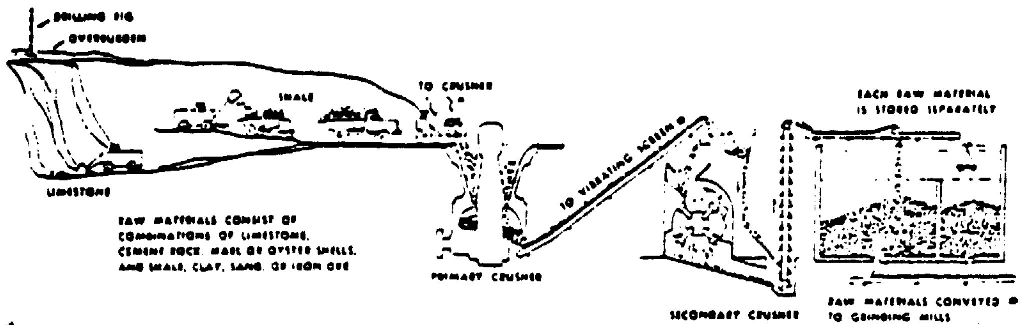
Complete power failure in a cement plant will most likely lead to damage to the refractory brick lining of the kiln, due to uneven heating and cooling when the kiln rotation stops. Any significant brick damage can soon lead to collapse of the refractory lining, necessitating a plant shutdown for complete kiln relining. It is, however, impossible to place a specific limit on the duration of a power failure which could be tolerated: a rough estimate might be around 5 minutes.

A partial power failure, or a reduction in power availability requiring some load shedding, could in principle be acceptable. A significant proportion of the plant load is taken by raw material and final product grinding mills, and loss of either service is not immediately

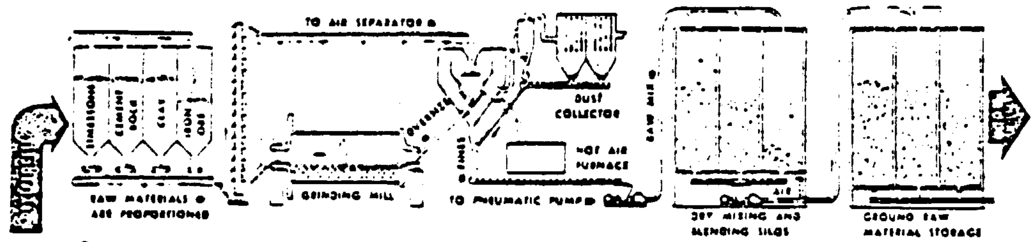
critical to the operation of the kiln. It is usual for some ground raw material and some clinker, in addition to the final cement product, to be stored in silos within the plant, and therefore kiln operations can be expected to continue for several hours without the need to restart the grinding mills. At worst, a partial power failure should allow the plant to carry out an orderly shutdown with no permanent damage to equipment. The critical services within a plant are most closely associated with the kiln itself, such as kiln rotation and combustion air blowers.

EXHIBIT 3241-1

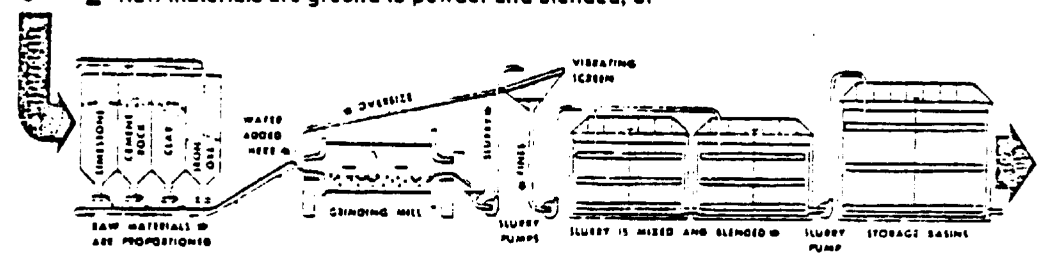
STEPS IN THE MANUFACTURE OF PORTLAND CEMENT



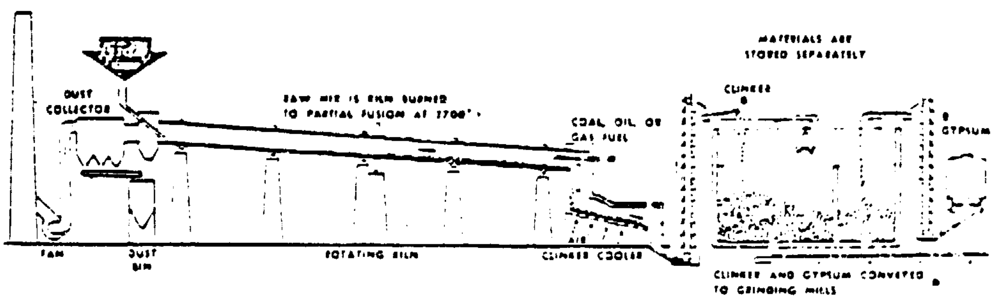
1 Stone is first reduced to 5-in. size, then ¾-in., and stored.



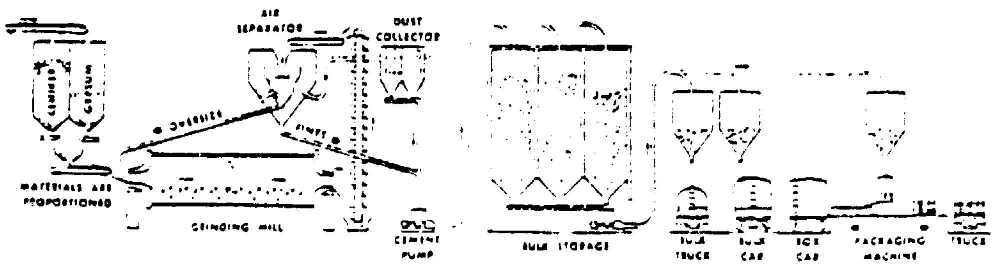
OR 2 Raw materials are ground to powder and blended, or



2 Raw materials are ground, mixed with water to form slurry, and blended.

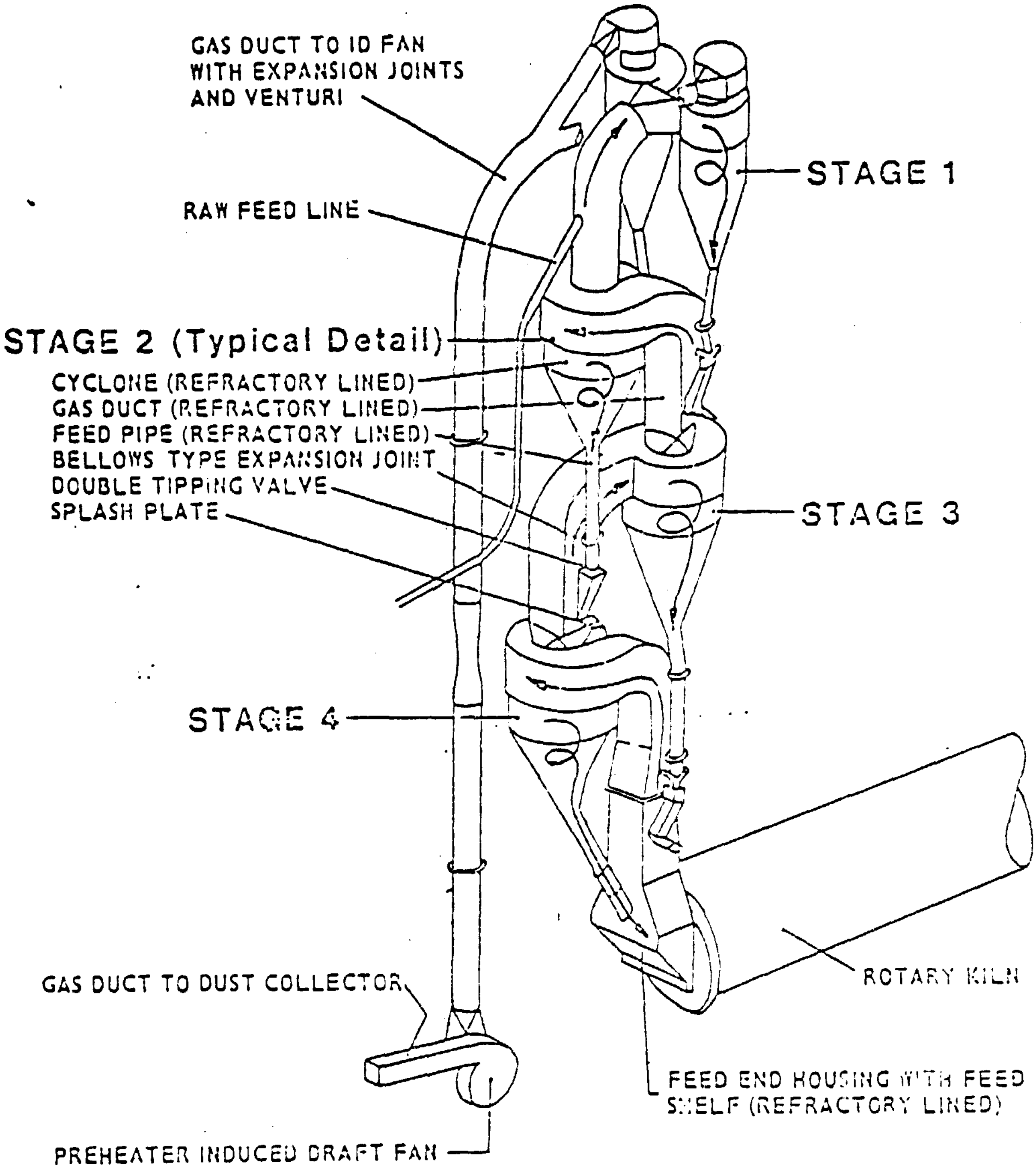


3 Burning changes raw mix chemically into cement clinker.



4 Clinker with gypsum is ground into portland cement and shipped.

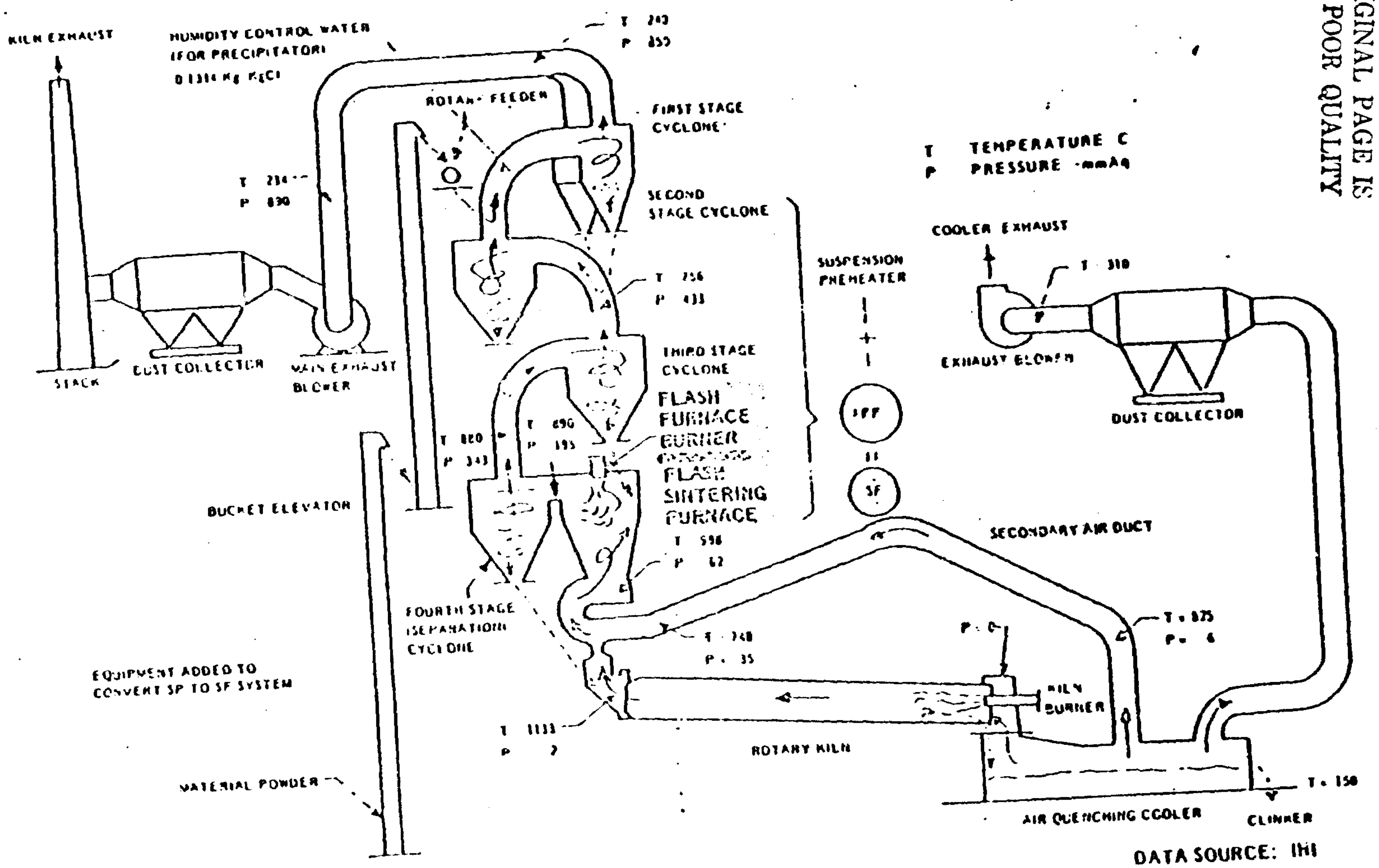
Source: Portland Cement Association.



DATA SOURCE: Fuller Company

SUSPENSION PREHEATER KILN 4-STAGE

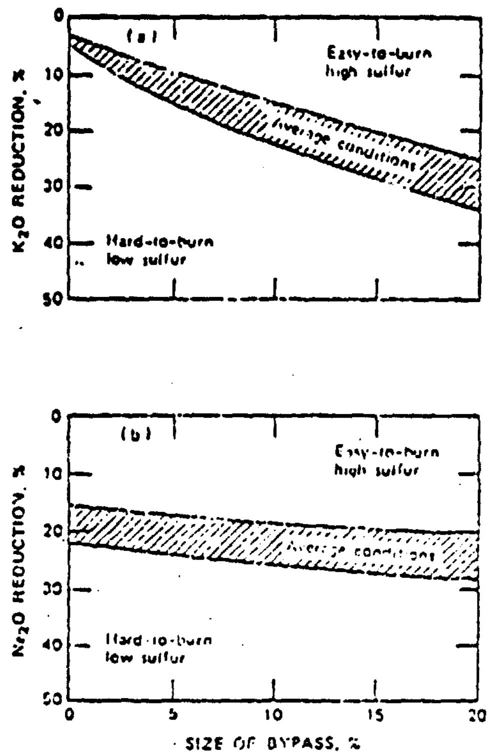
EXHIBIT 3241-2

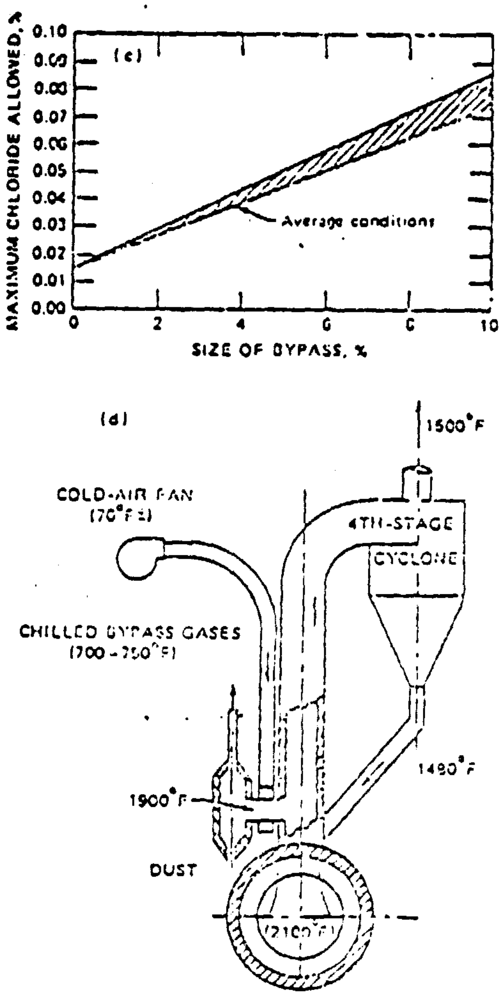


Flow Sheet of Rotary Kiln with Suspension Flash Preheater

EXHIBIT 3241-3

EXHIBIT 3241-4





Alkali and chloride removal with bypass for four-stage suspension-preheater kiln. (a) and (b) Bypass size vs. reduction. (c) Bypass size vs. allowed chloride. (d) Bypass arrangement. [From H. R. Norbem, Wet or Dry Process Kiln for Your New Installation? Rock Products: May 1974, p. 56.]

EXHIBIT 3241-5

ANNUAL NATIONAL DATA 1975), CEMENT INDUSTRY

Product Production-Million Ton*	Total Energy Consumption Trillion Btu	Purchased Electricity-Trillion Btu**	Purchased Fuels Trillion Btu	Coal/Coke	Oil	Gas	Other	Total Energy Consumption for SIC Trillion Btu	Percent Total Energy Consumption Represented
62.8	413.8	29.4	384.4	182.9	36.0	165.5	-	424.6	97.5

* Equivalent tons as defined in Section 2.2

** at 3413 Btu/kWh

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EXHIBIT 3241-6

CEMENT COMPANY CAPACITIES*

RANK	CEMENT (1000 TON)	PERCENT INDUSTRY	NAME
1	6,370	6.7	Ideal
2	5,217	5.5	General
3	5,125	5.4	Martin Marietta
4	4,493	4.7	Lone Star
5	4,268	4.5	Marquette
6	4,084	4.3	Amcord
7	3,856	4.1	Medusa
8	3,806	4.0	Universal Atlas
9	3,743	3.9	Kaiser
10	3,482	3.7	National Gypsum
11	3,030	3.2	California Portland
12	2,955	3.1	Lehigh
13	2,660	2.8	Southwestern
14	3,630	2.8	Missouri Portland
15	2,580	2.7	Citadel
16	2,217	2.3	Penn-Dixie
17	2,180	2.3	Louisville
18	2,150	2.3	Dundee
19	2,140	2.3	Flintkote
20	2,050	2.2	Alpha
21	1,550	1.6	Atlantic
22	1,504	1.6	Texas Industries
23	1,410	1.5	Gifford-Hill
24	1,306	1.4	Ash Grove
25	1,200	1.3	River
26	1,130	1.2	Coplay
27	1,125	1.2	OKC
28	1,120	1.2	Santee
29	1,050	1.1	Northwestern States
30	1,041	1.1	Centex
31	1,000	1.1	Maule
32	942	1.0	Columbia
33	855	0.9	Giant
34	850	0.9	Arkansas Cement
35	840	0.9	Oregon Portland
36	790	0.8	Whitehall
37	750	0.8	Hudson
38	725	0.8	National Cement
39	700	0.7	Monolith
40	660	0.7	Keystone
41	600	0.6	Monarch
42	570	0.6	South Dakota Cem.
43	565	0.6	Gulf Coast
44	560	0.6	Fla Mining/Mat'l
45	495	0.5	Rinker Portland Cem.
46	450	0.5	Cyprus Hawaiian Cem.
47	400	0.4	Wyandotte
48	390	0.4	San Antonio Port.
49	355	0.4	Capitol Aggregates
50	350	0.4	Utah Portland
51	282	0.3	National Portland
52	270	0.3	Jefferson Marine
Total	94,871		

* Includes gray, white and grinding only facilities.

SOURCE: Economic Research Department, Portland Cement Association
Old Orchard Road, Skokie, Illinois 60075 December 31, 1976

EXHIBIT 3241-7

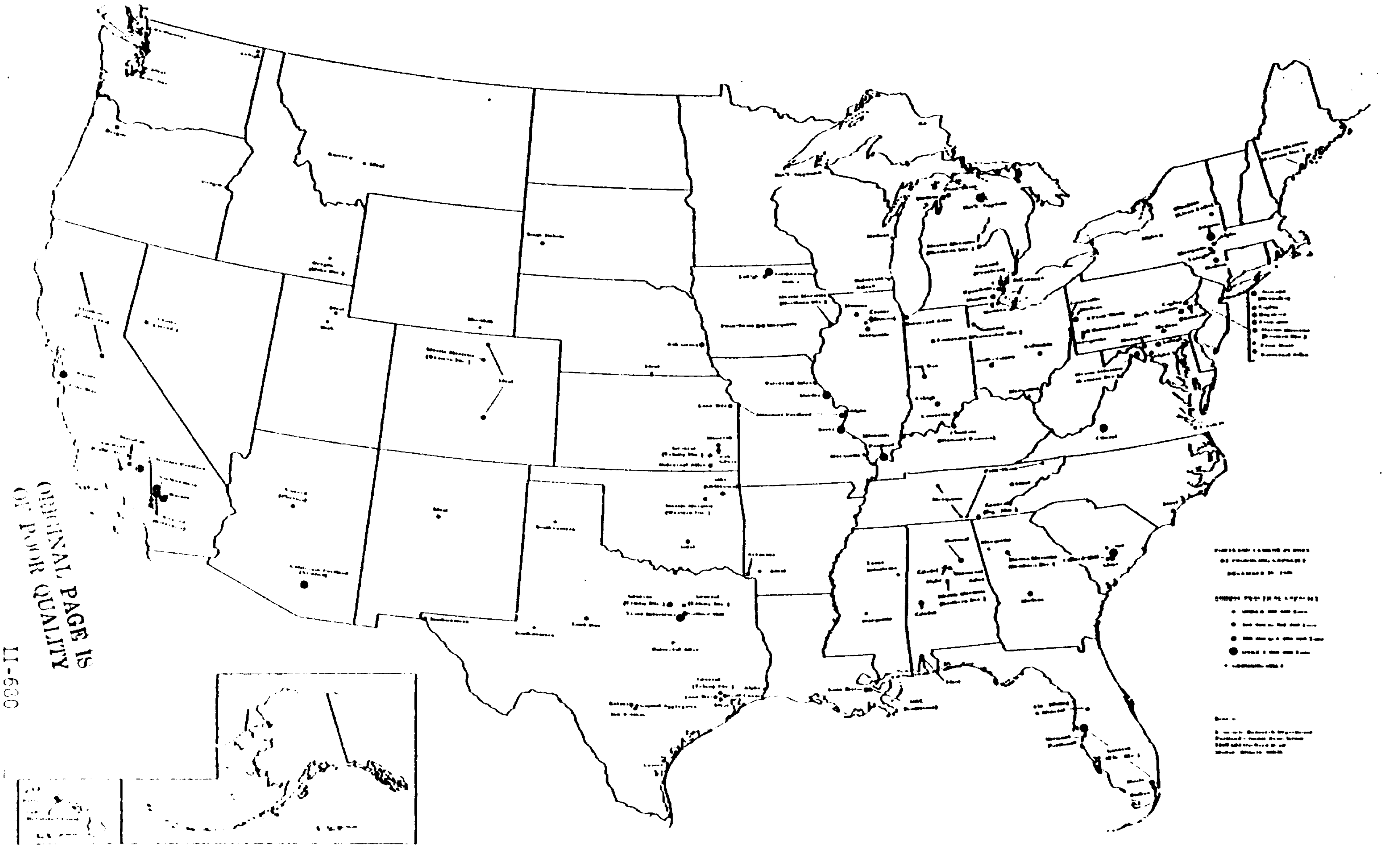


EXHIBIT 3241-8

STATE CEMENT PLANT CAPACITIES

RANK	CEMENT (1000 TON)	STATE
1	10,095	California
2	9,499	Pennsylvania
3	8,928	Texas
4	6,442	Michigan
5	4,956	Missouri
6	4,684	New York
7	3,957	Florida
8	3,902	Alabama
9	3,496	Indiana
10	3,093	Iowa
11	2,810	Illinois
12	2,539	South Carolina
13	2,451	Ohio
14	2,386	Kansas
15	2,004	Tennessee
16	1,861	Maryland
17	1,789	Washington
18	1,720	Arizona
19	1,714	Colorado
20	1,698	Oklahoma
21	1,683	Georgia
22	1,530	Virginia
23	1,245	Arkansas
24	1,089	Louisiana
25	1,025	Nebraska
26	935	West Virginia
27	770	Hawaii
28	710	Utah
29	664	Mississippi
30	660	Kentucky
31	650	Montana
32	630	Oregon
33	610	North Carolina
34	570	South Dakota
35	472	Maine
36	420	New Mexico
37	400	Nevada
38	374	Wisconsin
39	210	Idaho
40	200	Wyoming
TOTAL	94,871	

THERE ARE NO CEMENT PLANTS IN THE FOLLOWING STATES:

Alaska
Connecticut
Delaware
Dist. Columbia
Massachusetts
Minnesota
New Hampshire
New Jersey
North Dakota
Rhode Island
Vermont

SOURCE: Economic Research Department, Portland Cement Association
Old Orchard Road, Skokie, Illinois 60076 December 31, 1976

EXHIBIT 3241-9

KILN SIZE SUMMARY
(Capacities in 1000 Tons)

	WET			DRY			TOTAL		
AGE	NO. KILNS	CLINKER CAPACITY	AVERAGE CAPACITY PER KILN	NO. KILNS	CLINKER CAPACITY	AVERAGE CAPACITY PER KILN	NO KILNS	CLINKER CAPACITY	AVERAGE CAPACITY PER KILN
1976	0	0	0.0	6	3,086	514.3	6	3,086	514.3
1971-1975	14	5,772	412.3	20	9,402	470.1	34	15,174	446.3
1966-1970	24	8,960	373.3	10	3,833	383.3	34	12,793	376.3
1961-1965	24	8,561	356.7	23	[illegible],171	311.8	47	15,732	334.7
1956-1960	49	10,702	218.4	33	7,305	221.4	82	18,007	219.6
1951-1955	27	4,815	178.3	32	5,029	157.2	59	9,844	166.8
1946-1950	26	3,979	153.0	10	1,265	126.5	36	5,244	145.7
1941-1945	7	1,187	169.6	2	264	132.0	9	1,451	161.2
1936-1940	5	1,192	238.4	2	314	157.0	7	1,506	215.1
1931-1935	2	402	201.0	4	276	69.0	6	678	113.0
BEFORE 1931	36	3,758	104.4	29	2,511	86.6	65	6,269	96.4
TOTAL	214	49,328	230.5	171	40,456	236.6	385	89,784	233.2

AVERAGE KILN AGE (YEARS)

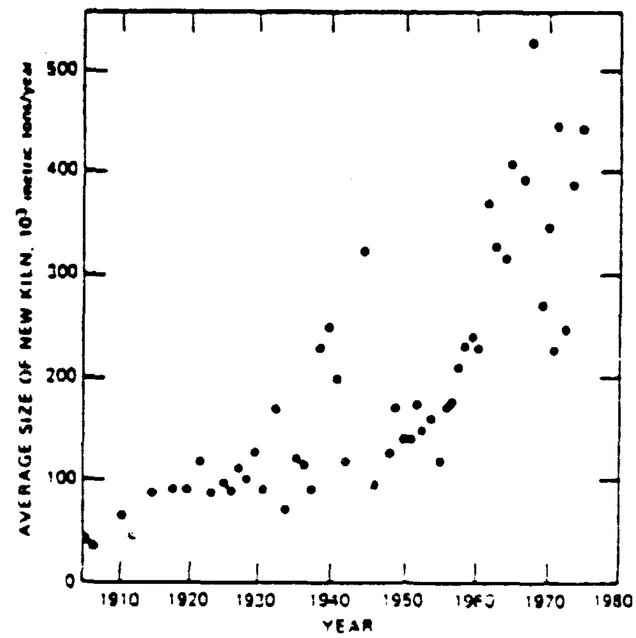
	WET	DRY	TOTAL
BASED ON NUMBER OF KILNS	1951	1952	1952
BASED ON CLINKER CAPACITY	1957	1961	1959

CAPACITY SUMMARY

	GRAY	WHITE	GRINDING	TOTAL
CEMENT	92,588	690	1,593	94,871
CLINKER	89,131	653	0	89,784

SOURCE: Economic Research Department, Portland Cement Association, Old Orchard Road, Skokie, Illinois 60076
December 31, 1975

EXHIBIT 3241-10



Average size of kilns added in specific years (U. S. data).

EXHIBIT 3241-11

ENERGY REPORT

U.S. PORTLAND CEMENT INDUSTRY

	1972	1973	1974	1975	1976	1977 1st 6 months
Production (10^6 eq. tons)	75.3	76.3	75.8	62.8	67.1	32.25
Btus (10^{12})	508.1	515.0	503.0	413.8	425.2	202.2
Energy usage (10^6 Btu/ton)	6.75	6.75	6.64	6.59	6.34	6.27
Percent improvement from 1972	Base Year	-0-	+1.7%	+2.4%	+6.1%	+7.1%
Credit[1]	-	-	-	-	+ .6%	+ .6%
Total improvement	-	-0-	+1.7%	+2.4%	+6.7%	+7.7%

1 Power used to operate pollution control and coal-handling equipment.

Source: Portland Cement Association Economic Research Department

EXHIBIT 3241-12

ENERGY USAGE BY TYPE
(in percent)

	1972	1973	1974	1975	1976	1977 1st 6 months
Natural gas	45.4%	43.2%	42.7%	40.0%	31.7%	22.9%
Petroleum products	12.1	13.9	10.7	8.7	10.2	12.0
Coal/coke	36.0	36.2	39.9	44.2	50.7	57.0
Electric power	6.5	6.7	6.7	7.1	7.4	8.1
TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Portland Cement Association Economic Research Department, September 1977

EXHIBIT 3241-13

ENERGY CONSUMPTION PER TON IN CEMENT PRODUCTION

Electricity Million Btu Per Ton	Hot Water Million Btu Per Unit	Steam (Million Btu/Unit)			Direct Fuel*** Million Btu Per Unit	Exhaust Stream	
		To 300°F	300-500°F	Over 500°F		Temperature °F	Energy Million Btu Per Unit
0.47	-	-	-	-	6.12	-	-
						430	0.98 w
						1100	1.34 d

EXHIBIT 3241-14

ENERGY CONSUMPTION PER UNIT OUTPUT IN CEMENT PRODUCTION[1]

	Industry Average	Best Practice Wet Process	Best Practice Dry Process	Best Practice Susp. Preheater[3]
Electricity[2]	0.5	0.5	0.5	0.5
Direct Fuel	5.8	4.7	3.1	2.7
Total [4]	6.3	5.2	3.6	3.2

Notes:

1. All data in million btu per ton of cement.
2. Electricity conversion factor 3413 btu per kWh.
3. Assumes no bypassing for alkali control.
4. Essentially no steam or hot water used in the manufacture of cement. Small amounts might be used in specific plants for space heating purposes.

EXHIBIT 3241-15

U.S. PREHEATER KILN INSTALLATIONS

Company	Plant	Capacity-TPY	Preheater Type	Manufacturer	Raw Mill	Online	Remarks
National Gypsum	Evansville, PA	90,000	4 Stage	Fuller	Ball	1953	Existing Plant
Whitehall	Cementon, PA	200,000	Suspension	Fuller		1955	Existing Plant
Medusa	Dixon, IL	130,000/ea	3-4 Stage	AC		1957	Existing Kilns
Amcord	Oro Grande, CA	180,000	4 Stage	AC	Ball	1959	Existing Plant
Amcord	Clarkdale, AZ	189,000/ea	2-2 Stage	FLS	Ball	1959	Existing Plant
Cyprus	Ewa Beach, HI	175,000	4 Stage			1960	Existing Plant
Whitehall	Cementon, PA	340,000	Suspension	Fuller		1964	Existing Plant
Lone Star	Davenport, CA	132,000/ea	3-ACL	AC		3-1971	Existing Kilns
Lone Star	Maryneal, TX	182,000/ea	3-4 Stage	Krupp		1971	Existing Kilns
Cyprus	Ewa Beach, HI	270,000	4 Stage			1972	Existing Plant
California	Rillito, AZ	600,000	4 Stage	AC	Ball	1973	Existing Plant
Flintkote	Glenns Falls, NY	565,000	4 Stage	AC	Roller	1973	Existing Plant
Monarch	Humboldt, KS	235,000	4 Stage	Fuller	Ball	1973	Existing Plant
Southwestern	Fairborn, OH	550,000	4 Stage	Fuller	Roller	1974	New Plant
Centex	LaSalle, IL	375,000	4 Stage	Fuller	Roller	1974	Existing Plant
Gifford-Hill	Harleyville, SC	562,000	4 Stage	Fuller	Ball	1974	New Plant
Flintkote	Kosmosdale, KY	640,000	Suspension	AC	Roller	1974	Existing Plant
Medusa	Clinchfield, GA	565,000	4 Stage	Fuller	Roller	1974	Existing Plant
Missouri	Joppa, IL	750,000	1 Stage	FLS	Ball	1975	Existing Plant
Florida Mining	Brooksville, FL	550,000	4 Stage	Polysius	Ball	1975	New Plant
Ash Grove	Louisville, NB	450,000	ACL	AC	Ball	1975	Existing Plant
Kaiser	San Antonio, TX	400,000	Suspension	Fuller	Roller	1975	Existing Plant
Whitehall	Cementon, PA	250,000	4 Stage	Fuller		1975	Existing Plant
Universal Atlas	Buffington, IN	297,000/ea	2-6 Stage	Fuller	Roller	1975	Existing Plant
Monarch	Humboldt, KS	265,000	4 Stage	Fuller	Ball	1975	Existing Plant
Amcord	Stockertown, PA	272,000	4 Stage	Polysius		1975	Existing Kiln
Universal Atlas	Leeds, AL	600,000	4 Stage	Fuller	Roller	1976	Existing Plant
Lone Star	Roanoke, VA	640,000	ACL	AC	Roller	1976	Existing Plant
National	Ragland, AL	550,000	4 Stage*	Fuller	Roller	1976	Existing Kiln
Lehigh	Mitchell, IN	250,000	1 Stage	FLS	Ball	1976	Existing Plant
Citadel	Demopolis, AL	750,000	4 Stage	AC	Roller	1977	Existing Plant
South Dakota	Rapid City, SD	565,000	4 Stage	Fuller	Roller	1977	Existing Plant
Louisville	Speed, IN	670,000	4 Stage	Fuller	Roller	1977	Existing Plant
Lehigh	Mason City, IA	500,000	4 Stage*	FLS		1978	Existing Plant
Centex	Buda, TX	500,000	4 Stage	Fuller	Roller	1978	New Plant
Coplay	Nazareth, PA	1,000,000	4 Stage	Polysius	Roller	1978	Existing Plant
Ideal	Boettcher, CO	450,000	ACL			1979	Existing Plant
Ideal	Knoxville, TN	575,000				1979	Existing Plant
Lone Star	Davenport, CA				Roller	1979	Existing Plant
Oregon	Huntington, OR		4 Stage			1979	Existing Plant
Marquette	Cape Girardeau, MO	1,000,000	4 Stage *	AC	Roller	1980	Existing Plant
Medusa	Charlevoix, MI				Roller	1980	Existing Kiln
Ideal	Theodore, AL	1,500,000				1981	New Plant

*Preheater with Flash Calciner

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EXHIBIT 3241-16

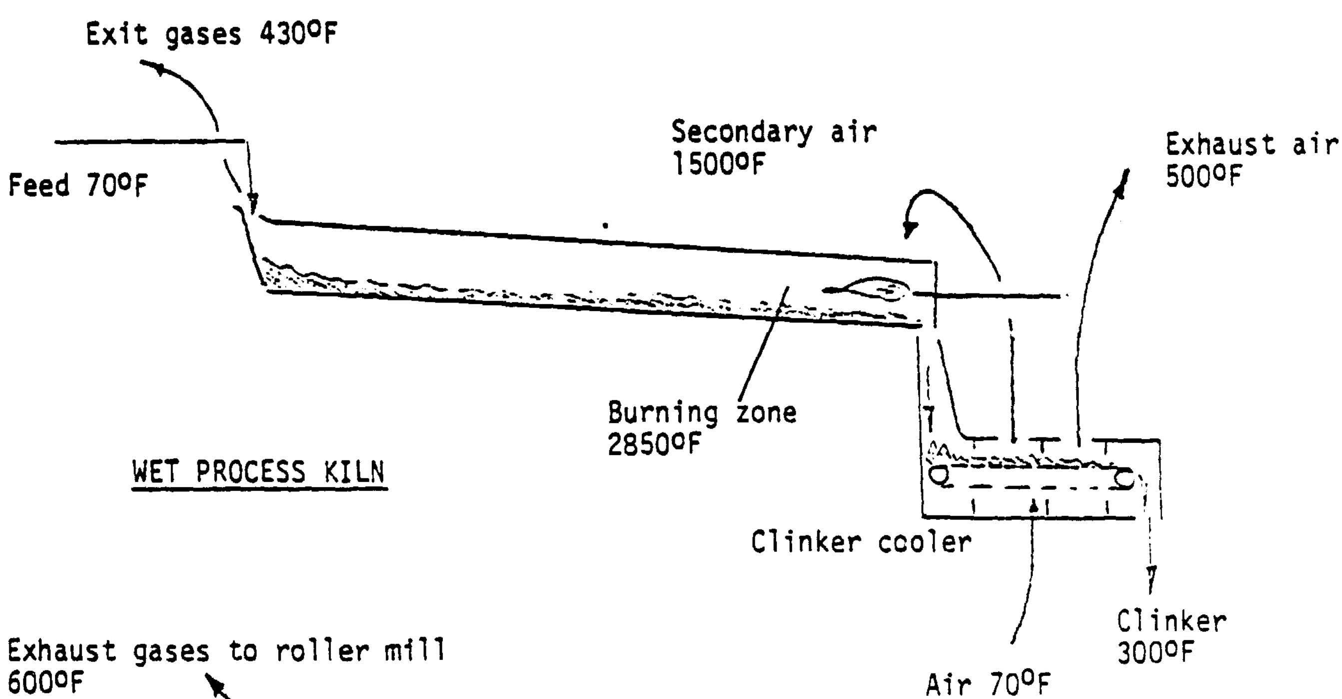
CEMENT PLANT FACTORS

TYPICAL PLANT CAPACITY TONS/YEAR	PLANT SIZE RANGE TONS/YEAR	ELECTRIC LOAD FACTOR	THERMAL ELECTRICAL COINCIDENCE FACTOR	PROJECTED APPLICABILITY TO 2000
550,000	170,000-2,322,000	0.90	1.0	*

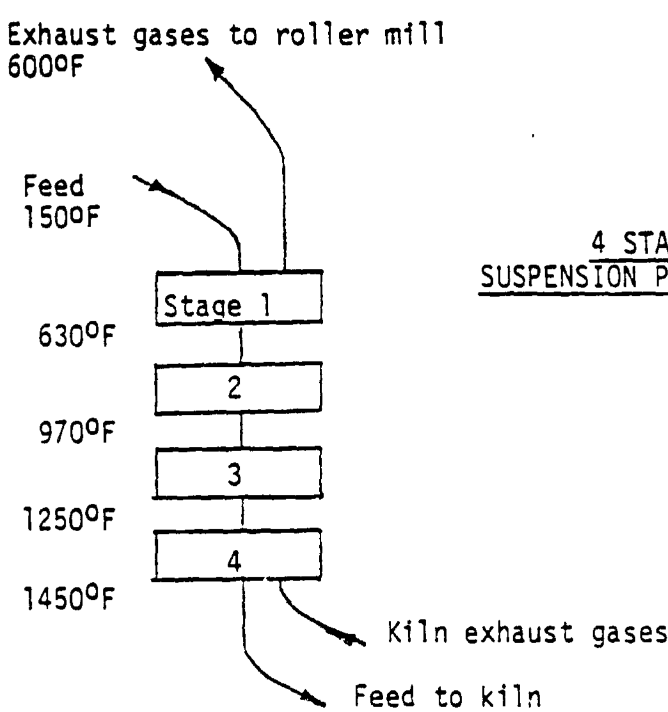
* Based on the discussion in section 2.1, modern preheater kilns are being designed at 2-4 times the capacity of typical existing kilns.

EXHIBIT 3241-17

REPRESENTATIVE TEMPERATURES



WET PROCESS KILN



4 STAGE SUSPENSION PREHEATER